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NASA PROJECT TECH

TECHNOLOGY UTILIZATION HOUSE STUDY REPORT

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INTRODUCTION

The homebuilding industry in the United States is a sophisticated blend of innovative technology and economics. Most of the practices and components used today have been developed and refined over many years to enable the builder to construct residences of reasonable cost with a practically infinite variety of designs and sizes.

Both builders and manufacturers must constantly strive for new methods and components if they are to survive in what is an extremely complex and competitive marketplace. The increasing consumer awareness of energy shortages and limited natural resources has placed additional constraints on an industry already burdened by high costs and interests rates.

Probably the most significant force for change in the building industry over the next few decades will be energy management. Our homes consume approximately 20 percent of the energy used in the United States each year; an amount nearly equal to all the crude oil we import. Numerous studies have been prepared on the subject and virtually all have recommended substantial changes in our residential energy use patterns. Clearly we cannot rapidly convert all our existing buildings to energy efficient structures but we can define the areas where they can be easily modified and we can find out how new structures can take advantage of cost effective components and techniques so that our future buildings will be designed to use energy as efficiently as possible.

Many of the techniques and components developed by NASA and private industry for the U.S. Aerospace program are applicable to the building industry. The objectives of Project TECH are:

1. Construct a single-family detached dwelling at Langley Research Center to demonstrate the application of advanced technology and to minimize the requirement for energy and utility services.

2. Help influence future development in home construction by defining the interaction of integrated energy and water management systems with building configuration and construction materials.

This report studies various components and methods which are believed to have a good chance of being cost-effective over the 20 year span of a typical home mortgage, assuming the generally accepted figure of a 10% increase in energy cost each year during that period. Components chosen for the Project TECH house are either now available to the building industry or are likely to be so before 1981. Some are in the development stage at this time but many are proven components.

In addition to building techniques and components, considerable emphasis in this study was placed on the design of the Project TECH house in order to take advantage of the natural heating and cooling available at its specific site (adjacent to the Visitors Center at NASA/LRC). Orientation and location of windows, landscaping,natural ventilation, and characteristics of the local climate and microclimate are intended to be used to best advantage. Various plan and spatial relationships were studied in order to maximize natural and mechanical heating and cooling characteristics.

It should be noted that energy conserving homes are most efficient when carefully designed to fit specific sites with their particular characteristics of access, orientation to sun and winds, their history of weather conditions and thermal requirements. For this reason Project TECH should not be considered a prototype or mass producible design suitable for all locations. Rather it should be a research and development laboratory containing many individual components, systems and ideas with methods of analysis which can be applied to some degree in all housing.

PROGRAM

The Project TECH house will consist of approximately 1500 sq.ft. of living space including a living room, kitchen-dining room, three bedrooms, two bathrooms and laundry, plus garage and outdoor living area.

Because of the ground water condition at the site (3' to 7' below surface) the house is built over a crawl space rather than a full basement.

The house is designed to make maximum energy saving and cost-effective use of NASA and industry developed components without requiring a substantial change in the lifestyle of the occupants.

The house is to be occupied by a family for at least one full year after its completion and will then be open to the public.

Space heating and cooling will be provided by a solar collector/radiator system with thermal storage. This system, and the waste-water partial reclamation system, are both designed by NASA/LRC for this demonstration project.

METHODS AND AREAS OF STUDY

CHAPTERS

1. The A/E design team wrote letters to approximately 250 manufacturers and organizations, who are known to be involved in energy conservation in the building industry, requesting information on products or ideas which might be applicable to Project TECH. A library of reference material on energy conserving design was assembled.

2. "Technology components" were evaluated by the NASA team and by the A/E.

3. The A/E design team prepared study designs for a one-story residence and a two-story residence. Both were evaluated for thermal efficiency and for other program requirements.

4. The A/E design team made cost vs. thermal performance studies of various wall sections, roof sections, floor sections and window types to determine which components and assemblies provided the greatest net savings.

5. The value of the solar heating and cooling systems were analyzed in the same manner as assemblies and components, except that certain parts of these systems are essentially custom-made and therefore their cost may actually decrease over the next five years if they are mass produced in a competitive market.

6. Heat loss calculations for the proposed designs were analyzed and annual heat costs were projected as if the houses were to be heated by conventional air to air heat pumps. Estimated energy costs using solar space heating and cooling were prepared.

7. The effect of energy conservation on occupant life-style (and vice-versa) was studied since other studies have shown that energy consumption can vary widely from family to family. An information display system, which shows the occupant where and how energy is used in the home, has been recommended for Project TECH.

8. Waste water reclamation systems were designed by the NASA team.

9. The NASA team evaluated the amounts of heat which appliances could contribute to the annual heating requirements and the A/E design team recommended certain specific ways in which appliance heat could be retained or vented as necessary. Appliances were recommended for their energy saving characteristics.

10. Sun angles were calculated and overhangs provided to minimize sunlight entering through the south windows between April and September while making provision for the collection and use of the sun's heat (insolation) during the winter months.

11. Siting and orientation of the residence was studied with the intention of using natural ventilation as far into the spring and summer as possible and again as early in the fall as possible in order to reduce the energy required for air conditioning.

12. Ventilation and infiltration were studied in order to determine how to reduce heat loss in winter and heat gain in summer.

13. Fireplaces which are often a net energy loss for residences, were designed to add heat to the storage system.

14. Costs for the construction of Project TECH were estimated for two conditions:

    a. The initial cost of the residence if built by a homebuilding contractor to sell to the homebuying public, assuming "mass production" prices for all components.

    b. The expected construction cost to NASA as a research and development facility, assuming that many components must be "custom made". Cost estimates for instrumentation and recording of data were prepared by the NASA team.

CHAPTER 1

INQUIRIES TO MANUFACTURERS AND ORGANIZATIONS AND LIBRARY OF REFERENCE MATERIAL

Letters of inquiry requesting information on energy and resource conservation in housing were mailed to more than 250 manufacturers and organizations known to be involved in the design or manufacture of energy conserving components or systems.

The mailing list was compiled by the A/E design team from publications and bibliographies on the subject. (Most manufacturers of building products are either actively engaged in research on energy conserving products or are considering such research in the near future.) Approximately 130 responses had been received up to the writing of this report and information contained in these responses was evaluated by the A/E design team during the process of component selection.

Because extensive testing of components was beyond the scope of this study the A/E design team based its recommendations on information supplied by manufacturers, testing organizations and their own experience. The A/E design team also assembled a small library of publications on the subject of energy conserving design and analysis. The following is a bibliography of those publications:

BIBLIOGRAPHY

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The Value of Thermal Insulation in Residential Construction - Economics and The Conservation of Energy - John L. Mayers, Oak Ridge National Lab. - 1971

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Penquin Books - 1974

Retrofitting Existing Housing for Energy Conservation: An Economic Analysis - National Bureau of Standards- Building Science Series 64 December 1974 (U.S. Govt. Printing Office Catalog No. C13.29:2/64)

CHAPTER 2

"TECHNOLOGY COMPONENTS"

A list of "technology components" was suggested for consideration. The items were evaluated by the A/E design team and the NASA team to determine which were appropriate for installation and further use-testing in the Project TECH house. The results of that evaluation are as follows:

1. Flat conductor cable system recommended for use as power conductors in a baseboard enclosure system in living room and bedrooms. Also recommended for use as switching circuit conductors for low voltage switching system for lights, switched outlets, thermostat control wiring and doorbells.

   Reasons:

   A. Current carrying capacity of flat cable conductor is greater than that of the equivalent cross sectional area of solid round wire.
   B. Use of F.C.Conductor in low voltage switching circuits substantially reduces the amount of copper required to wire a residence.
   C. Installation of baseboard-enclosed FCC circuits and surface applied switching circuits could substantially reduce electrical installation costs.

2. LAMINITE Lightweight board material - Not recommended for interior wall surface material but might have application as all or part of "Thermal Shutters" to reduce heat loss through windows

   Reasons:

   A. Shrinkage and expansion with changes in humidity make joining for smooth surfaces difficult.
   B. Denting or corner damage during shipping may cause substantial waste on job.
   C. More expensive than gypsum board
   D. Not as good as gypsum board for fire protection of structure.

3. Fire and Security Systems - Ionization smoke detectors and intrusion detectors are recommended with an integrated alarm system independent of electrical system of house.

   Reasons:

   A. Ionization type smoke detectors sense combustion products before they are noticeable to occupants, allowing adequate time for escape from building. (Most fire related deaths result from smoke inhalation)

B. An integrated fire-security system with strobe-lite indicator on roof would assist fire and police departments in locating residence in an emergency.
C. Automatic battery charging by house current assures that system will be operational during a power failure.
D. Solar battery charging is not cost-effective.

4. Solar Collectors/Nighttime Radiators with Heat Pump are recommended for the residential heating system although not presently cost effective.

Reasons:

A. Electricity as fuel will be available from various central sources; (petroleum, solar, gas, hydrogen, wind, etc.)
B. Heat pumps are substantially more efficient than electric resistance heat especially when used with a solar heat source.
C. Good climatic conditions exist at site for solar heat collection.
D. Further study and instrumentation of solar-heating/radiative-cooling systems is essential in order to refine designs.

5. Advanced Systems control concept is recommended.

Reasons:

A. Accurate control of heating and cooling systems can result in substantial energy savings.
B. Systems will become cost effective through development of Integrated Circuitry for heating system controls.

6. Waste water partial reclamation system is recommended.

Reasons:

A. Partial recyling of waste water can reduce demand on (and cost of) sewerage systems, treatment plants, water supply systems.
B. Such systems reduce damage to the environment.
C. Such systems are cost effective in areas where present types of systems are either marginal or impractical.

7. Fire extinguishing systems in key areas of house are not recommended.

Reasons:

A. Danger to occupants is inherent in systems which deprive oxygen from combustion.(Possible exceptions are detergent foams or water sprinkler systems.)

B. Major objective in case of fire is to get occupants out of the house before ignition occurs.
C. Difficulty in determining which areas to protect.
D. Accidental discharge of an extinguishing system could cause substantial damage or injury to people and property.

8. Heat pipe systems are recommended for recapture of heat from wastewater and possibly from fireplace flue.

Reasons:

A. Recapture of heat otherwise wasted can contribute to reduced energy use.
B. Heat pipes can efficiently transfer waste heat from the wastewater holding tank to the heat collection and storage system.

9. Emergency Lighting(solar cell powered) is not recommended.

Reasons:

A. Conventional emergency lighting systems, in which batteries are kept charged by house current until used, are advisable for public buildings or two story houses, when a power failure occurs concurrently with a fire or other emergency, in order to provide lighted exitways.
B. The added expense of charging batteries by solar cell could not be justified as cost-effective.

10. Intumescent paint for fire protection is not recommended.

Reasons:

A. Intumescent (inorganic paint which forms a protective foam when subjected to high temperatures) is designed to protect exposed metal structural components from failure in a fire. Such paint would provide no greater protection to a detached house than would gypsum board.
B. Intumescent paint gives off toxic gas when heated to a temperature high enough for it to function as a protective coating.

11. Special fire retardant materials for curtains, carpets, etc. are recommended.

Reasons:

A. Most residential fires start in the contents of the home rather than in the structure.
B. Curtains and wall materials have the greatest likelihood of flame spread because they are oriented vertically.

12. "Super" insulation is recommended where cost-effective and safe.

Reasons:

A. Plastic foam materials have a greater resistance to heat transfer than most other forms of insulation.
B. Urea formaldehyde and/or Urethane foams using isocyanates compounds are not recommended except when completely surrounded by fireproof material.
C. Urea tri-polymer foams ai recommended due to their fire-resistant qualities and good insulatine values.
D. Low flame spread styrofoam insulation is rec mmended where rigid board material may be necessary (perimeter insulation, etc.) and below grade.

13. "Kolamite" garage doors are not recommended.

Reasons:

A. Not cost effective

14. "Low noise" flow valves for air supply ducts are recommended if cost effective.

Reasons:

A. Smaller (less expensive) ducts supplying higher velocity air could be used if noise could be reduced.

15. Solid State appliance controls recommended for surface cooking unit if available.

FLAT CONDUCTOR CABLE

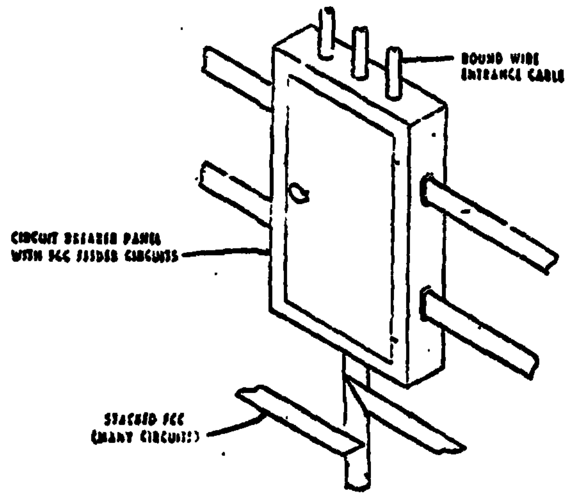


Figure 1. Circuit Breaker Panel

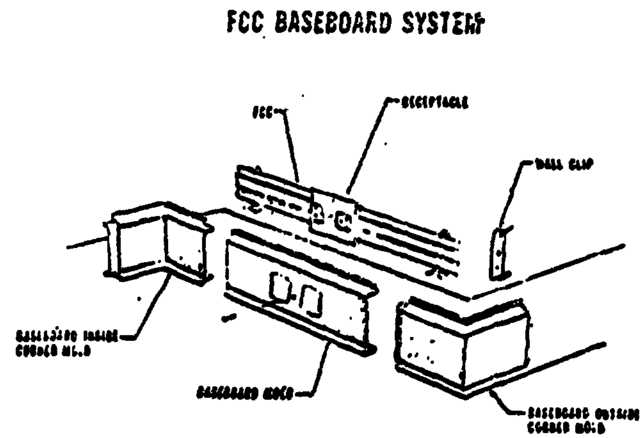


Figure 3. Snap-on Cover Baseboard System

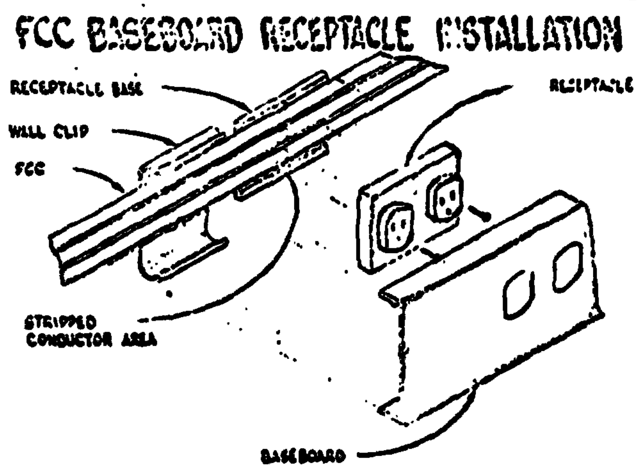


Figure 5. Receptacle with Pressure Contacts

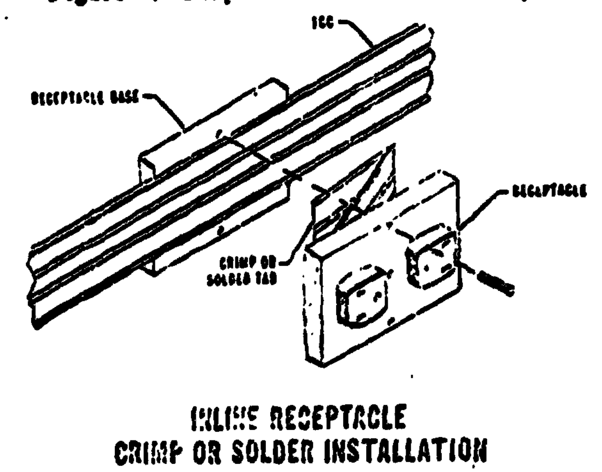
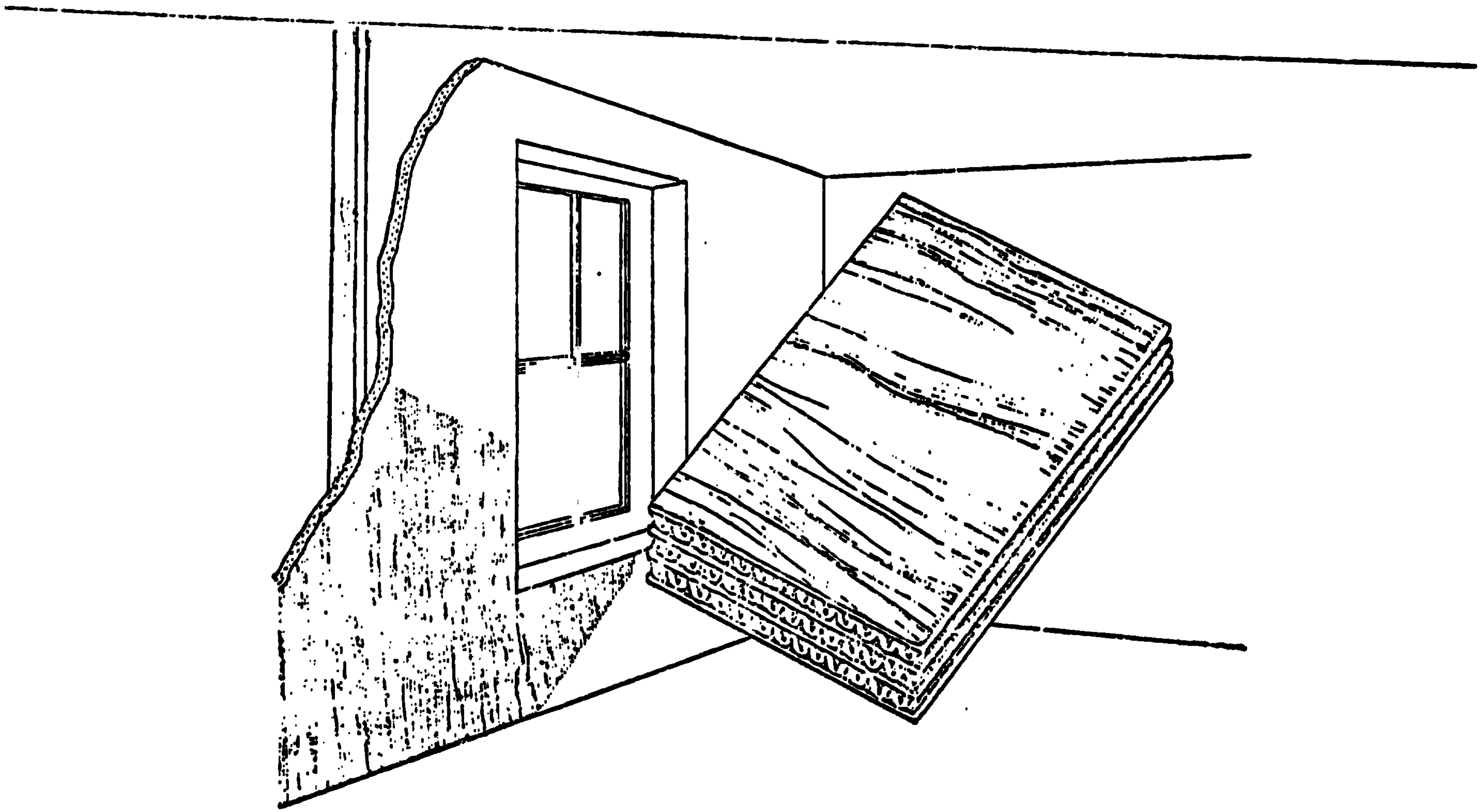
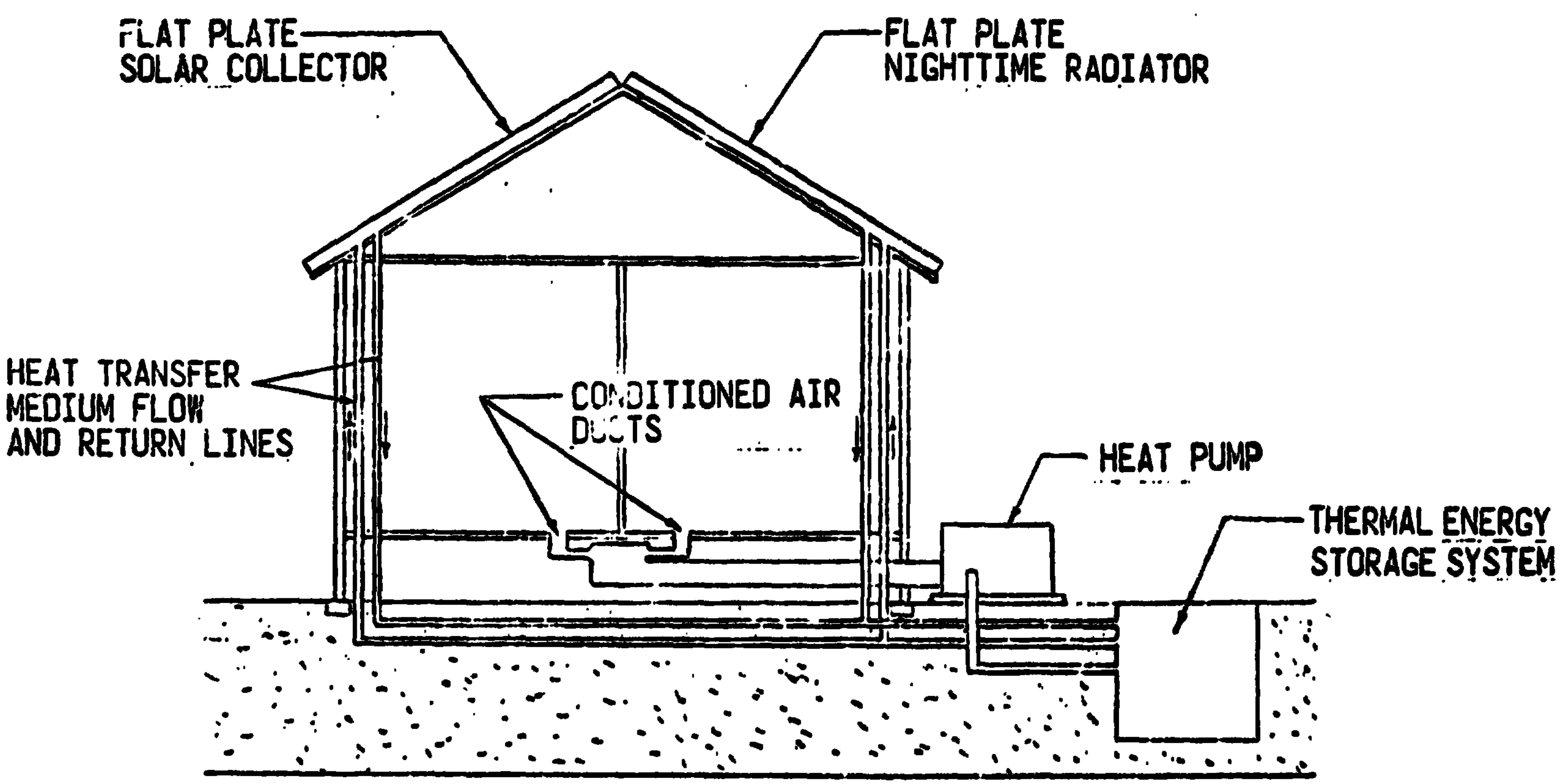


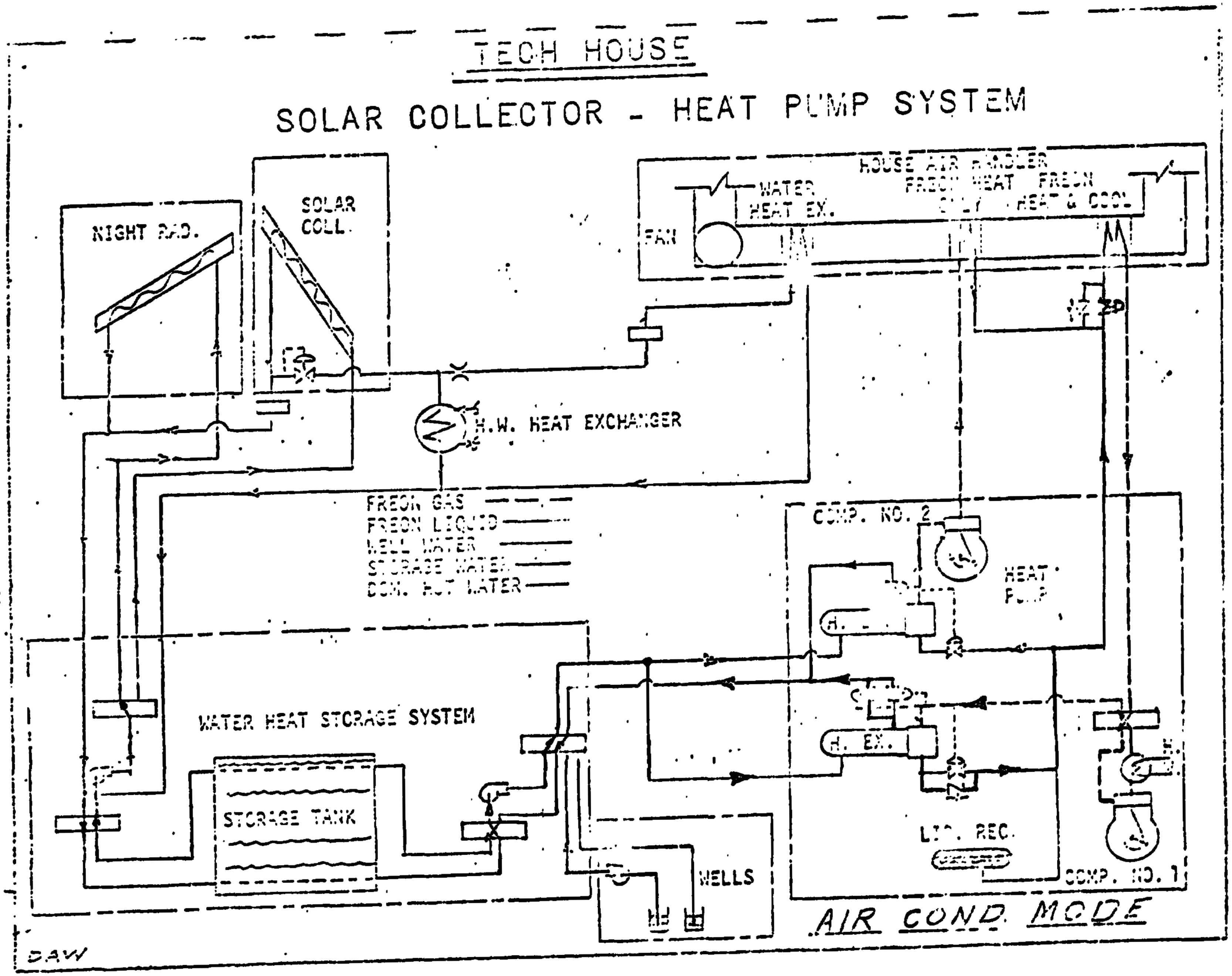
Figure 4. Receptacle with Crimp or Solder Tab



LAMINITE BOARD MATERIAL

SOLAR COLLECTOR SYSTEM

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SOLAR COLL.
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FREON GAS
FREON LIQUID
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STORAGE WATER
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COMP. NO. 2
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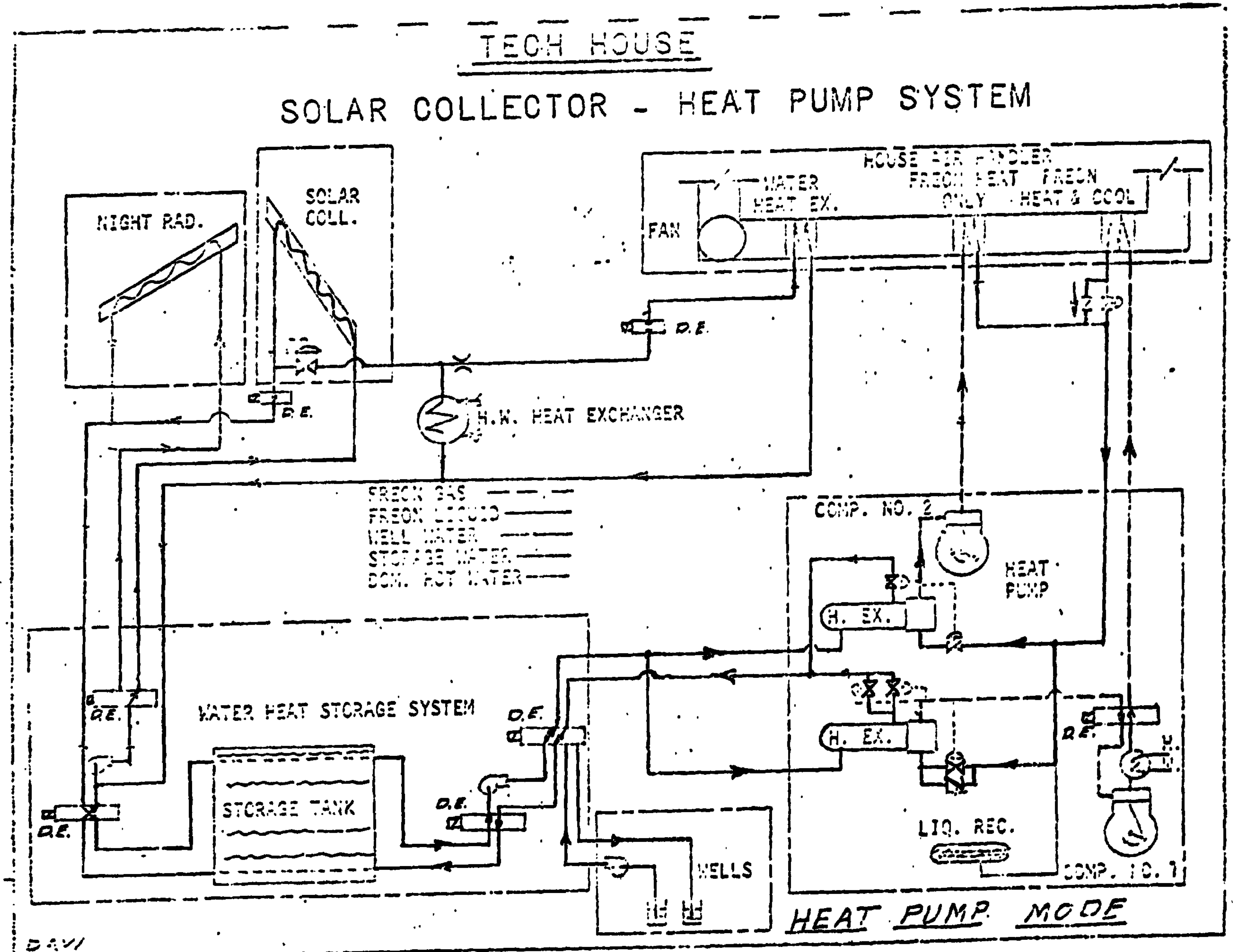
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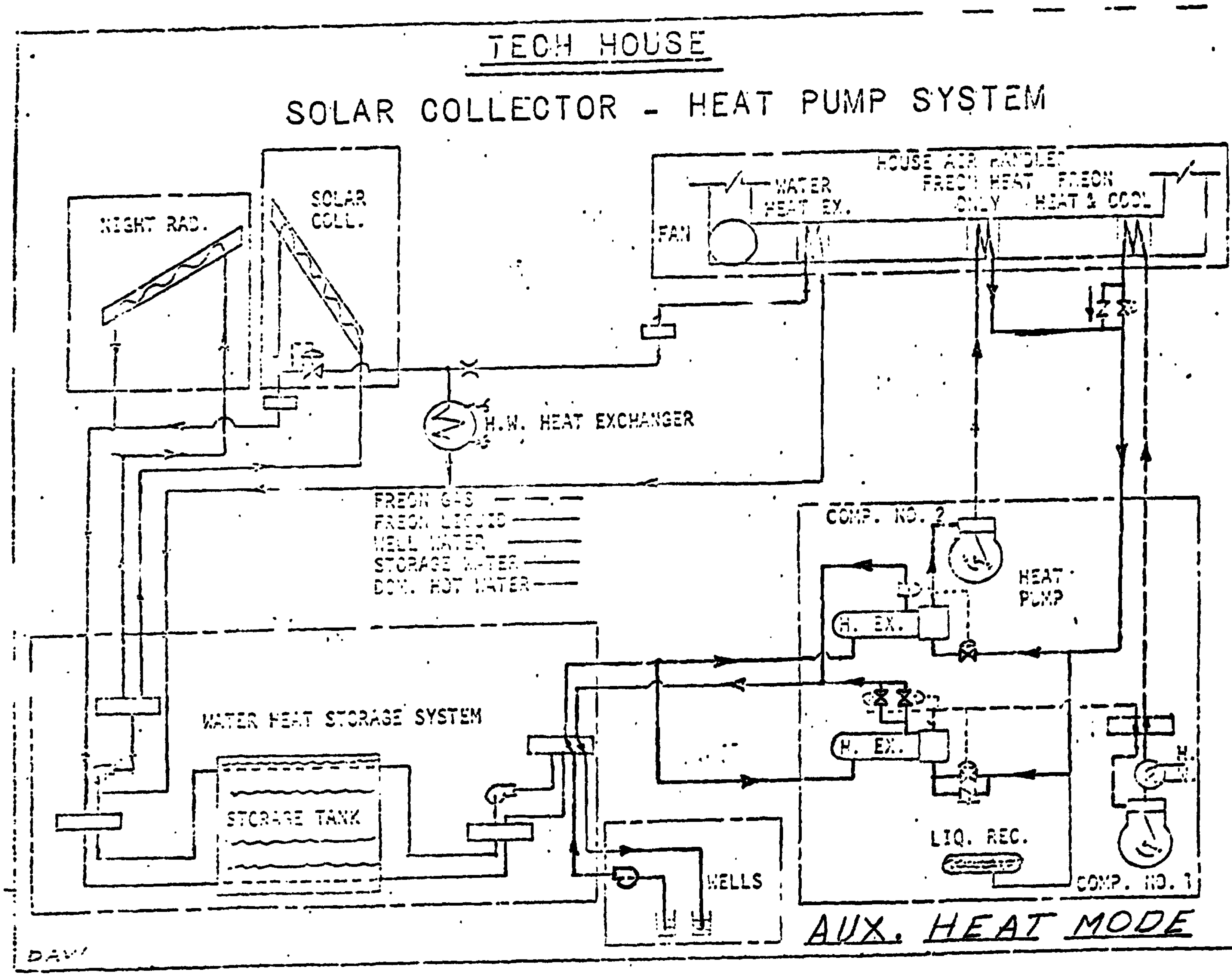

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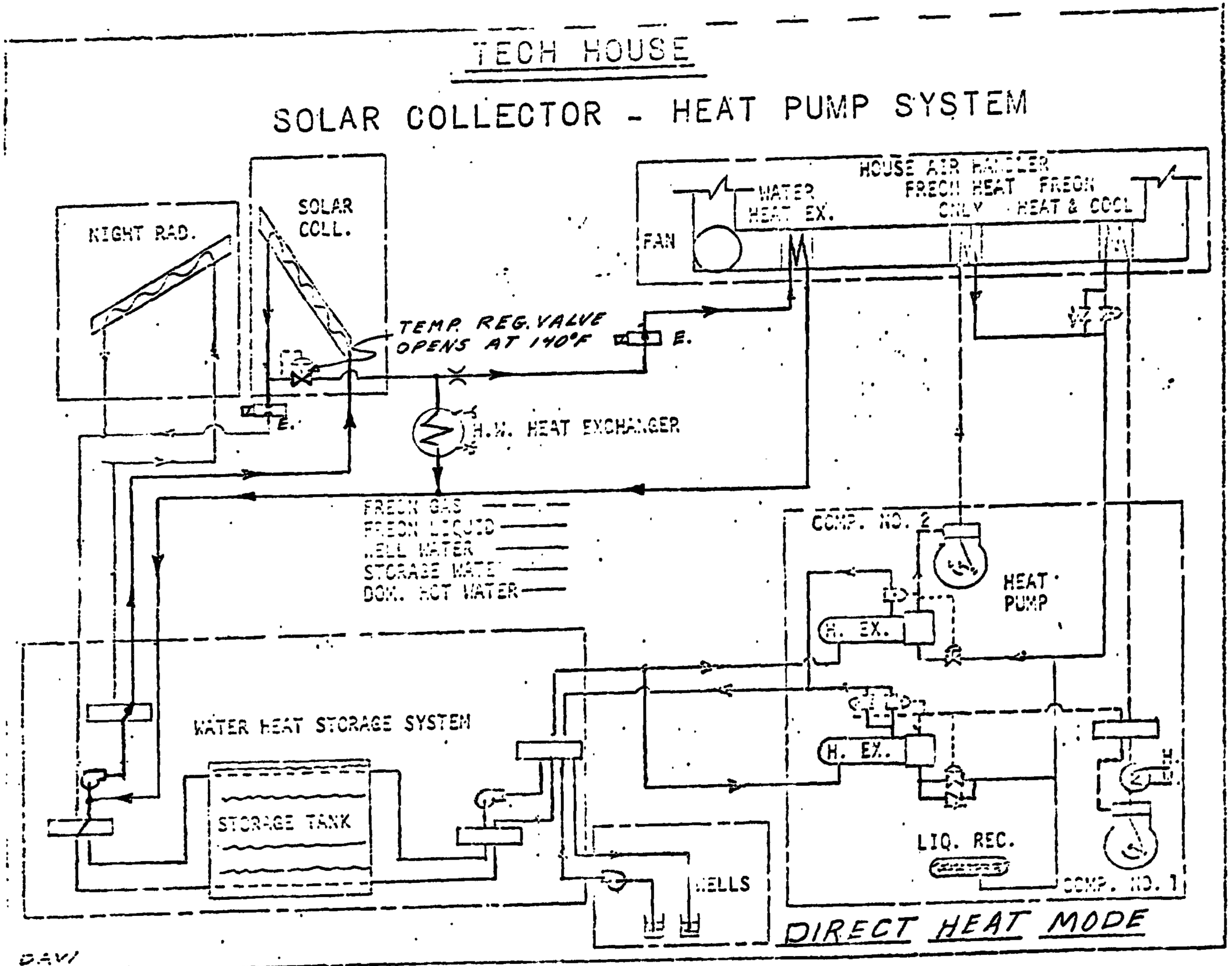
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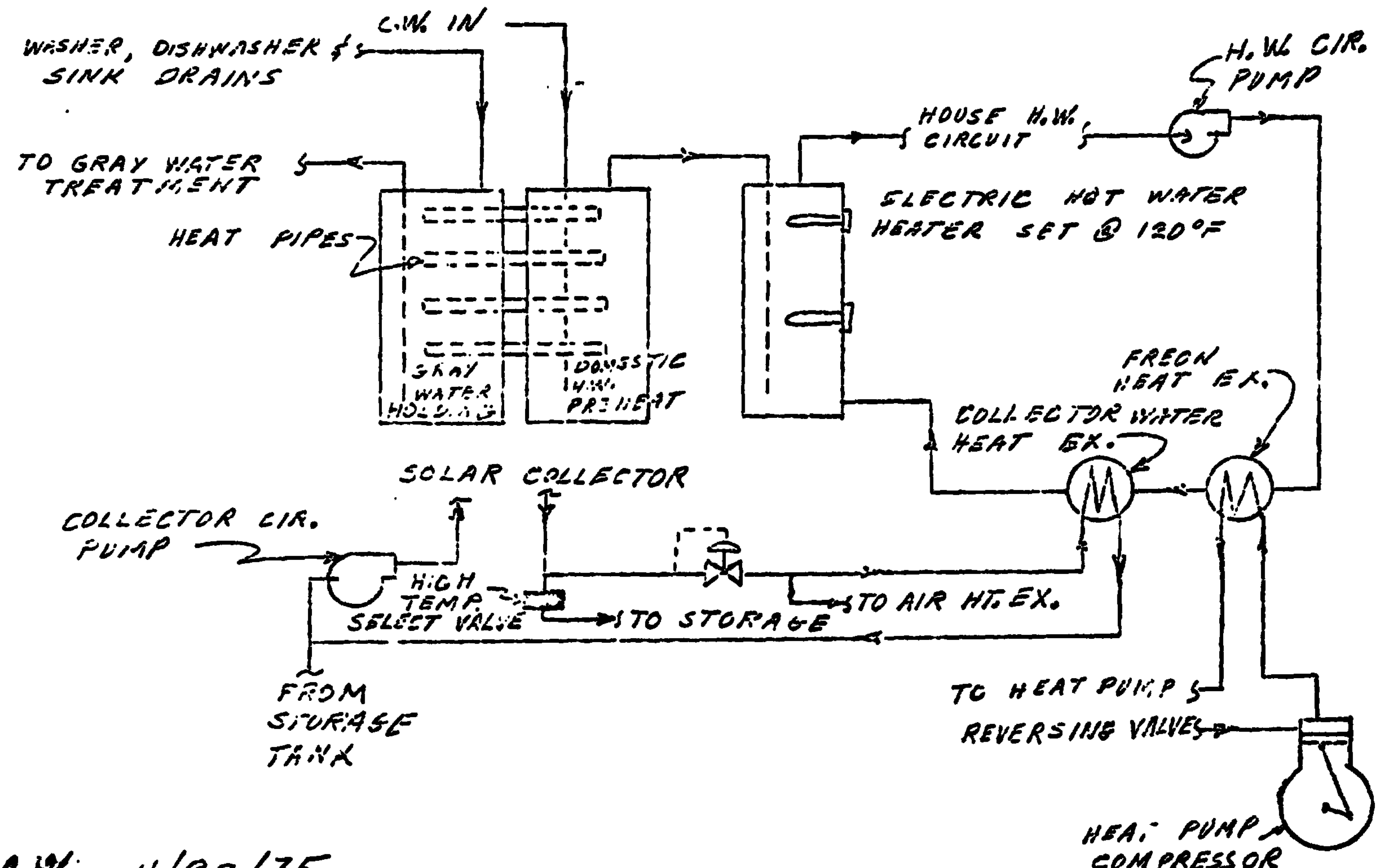
WATER HEAT STORAGE SYSTEM
STORAGE TANK
WELLS
DIRECT HEAT MODE

TECH HOUSE

Domestic Hot Water System



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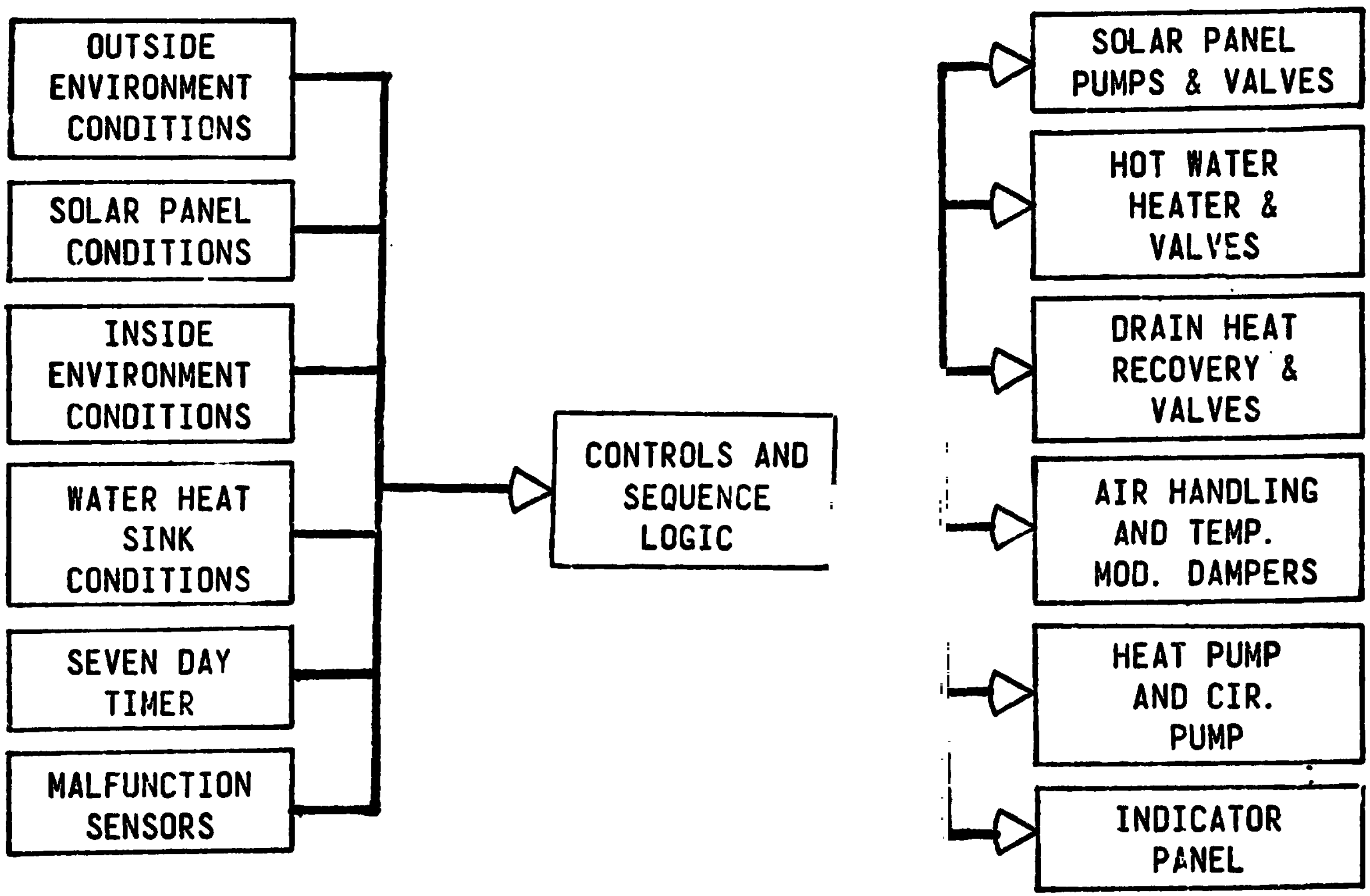
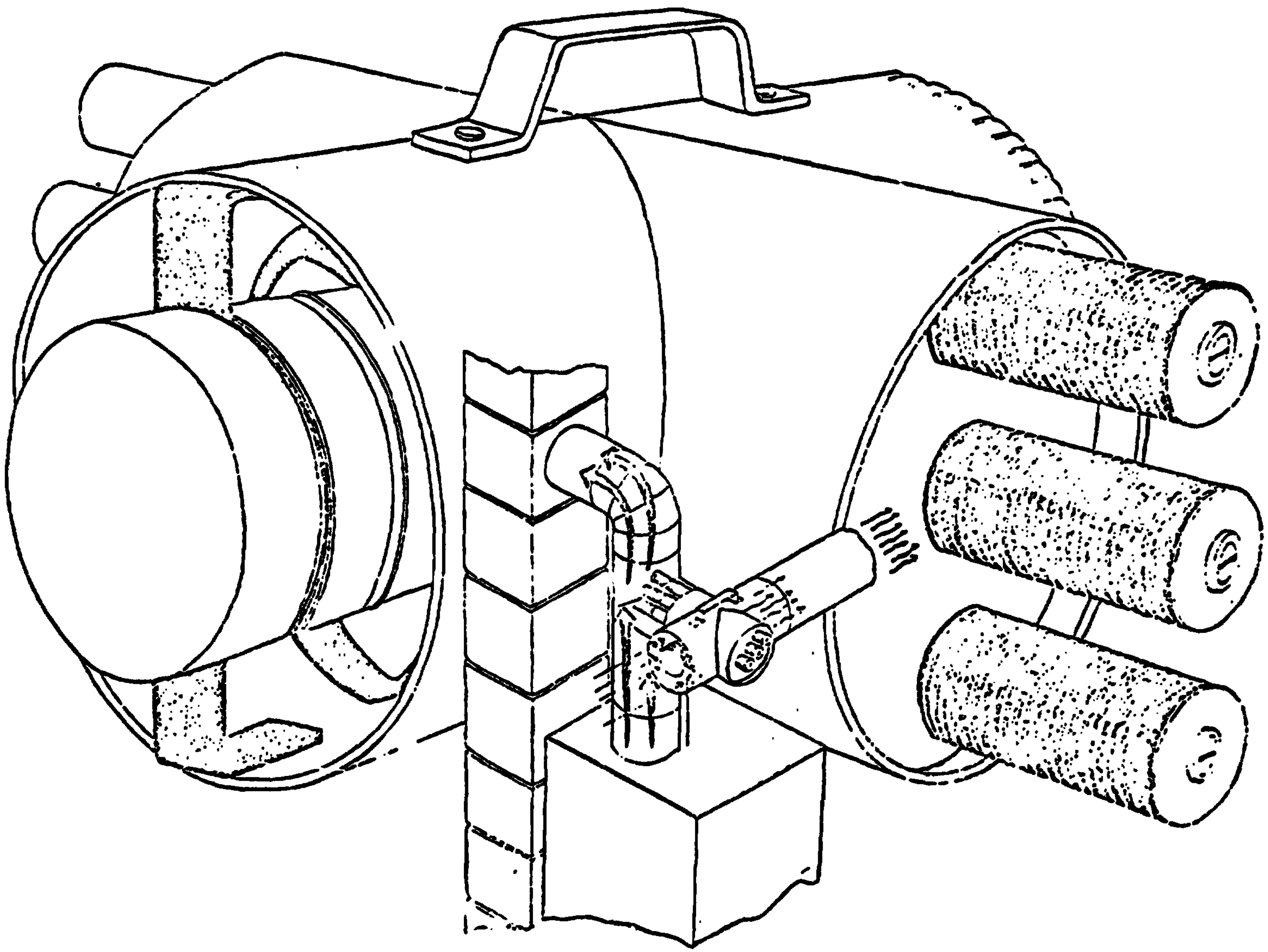
SYSTEMS CONTROL CONCEPT



HEAT PIPE



CHAPTER 3

STUDY DESIGNS

The A/E design team began by studying one and two story building shapes with regard to minimizing heat loss and maximizing heat gain (with a maximum number of south facing windows). This led to two basic building shapes; a compact, cubic shape for low heat loss design and a linear shape oriented east-west for high heat gain design. Since the heat gain minus heat loss was greater for the linear, gain type designs, this approach was further developed.

In order to consider the large number of variables involved in thermal analysis, such as orientation, site location, components and systems, the A/E design team chose to develop two initial study designs for analysis. These two designs were called HG1 and HG2 (for Heat Gain 1-story, and Heat Gain - 2 story).

Plans and elevations of the 2 study designs (both 1400 sq.ft. in floor area) were developed and heat loss calculations showed that while both were quite efficient, HG2 was about 14% to 18% better than HG1 when their estiamted annual heat losses were compared.

The possible annual heat gain of HG1 was, however, superior to HG2 due to the greater amount of glass area exposed to winter sun.

A modified version of HG1 was chosen for further analysis and development.

Reasons:

A. Substantial floor area in HG2 was taken up by stairs
B. A shorter and wider version of HG1 could reduce heat loss.
C. HG1 winter heat gain was greater than HG2.
D. Window shading was less expensive in HG1 than in HG2.
E. Circulation problems of opening the house to the public were reduced in a one-story version.
F. Mechanical systems are simplified in a one-story residence.

A study design called HG1B was then developed by the A/E design team. This version is more rectangular than HG1 and is essentially a "shed" structure which uses the solar collectors as the sun shading device for south facing glass areas.

Study design HG1C was a refined version of HG1B

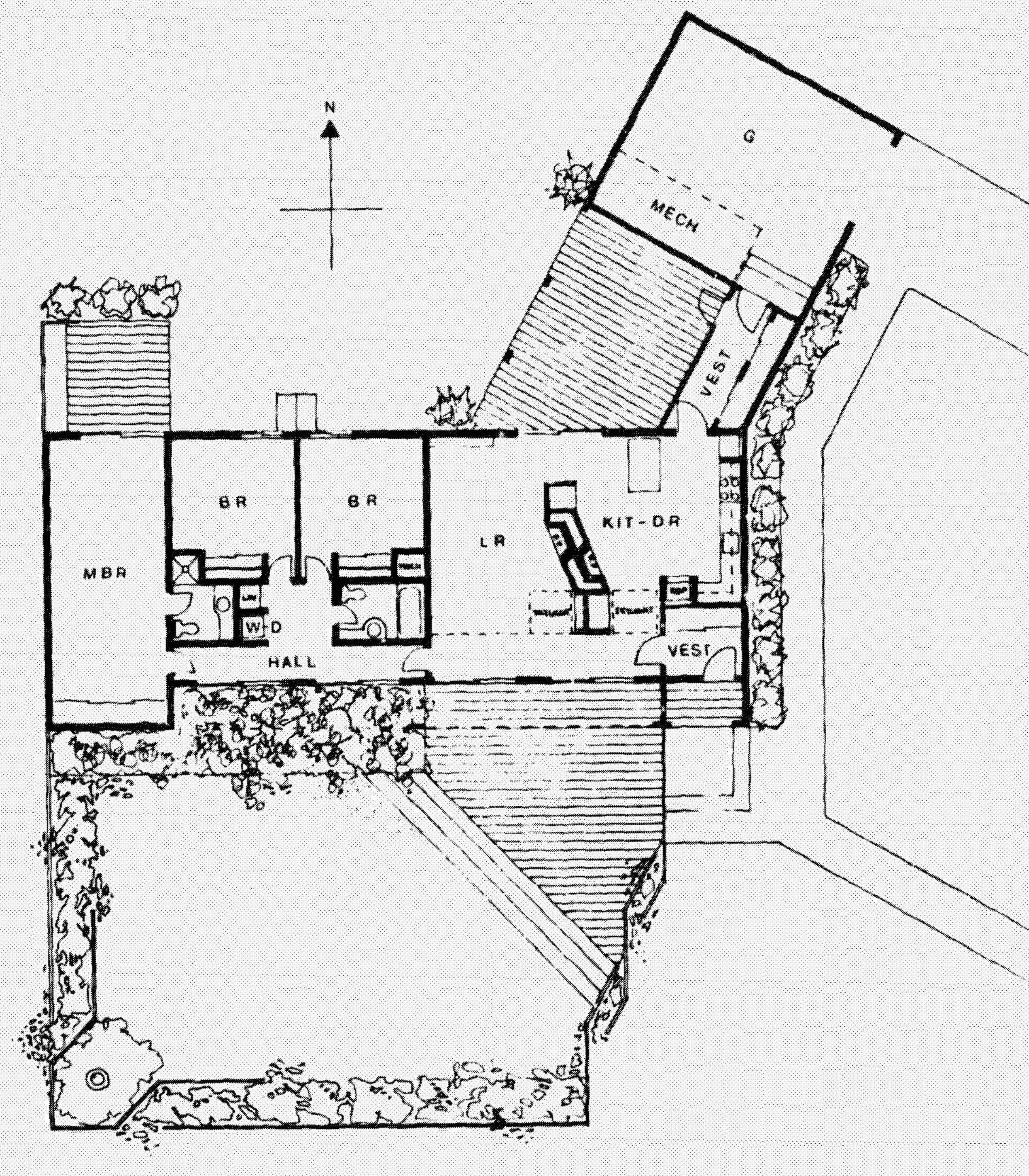
The final study design HG1D is a further refinement with 1500 sq.ft. of floor area.

Configuration of HG1D

1. Efficient rectangular shape with long axis oriented east/west.
2. Large south-facing glass areas.
3. Shading of south windows allows entry of winter sun, excludes summer sun.

4. Solar collectors act as sunshades.
5. Garage located to protect house from North wind.
6. One room depth for good cross ventilation.
7. Hallway acts as heat collector.
8. Plumbing of bathrooms centrally located.
9. 2 interior fireplaces for auxilliary heat.
10. "shed" structure for ease of construction.
11. Attic belvedere configuration to aid summer ventilation.

HG1D Floor Plan showing fenced yard and outdoor decks.



PROJECT TECH
HGID

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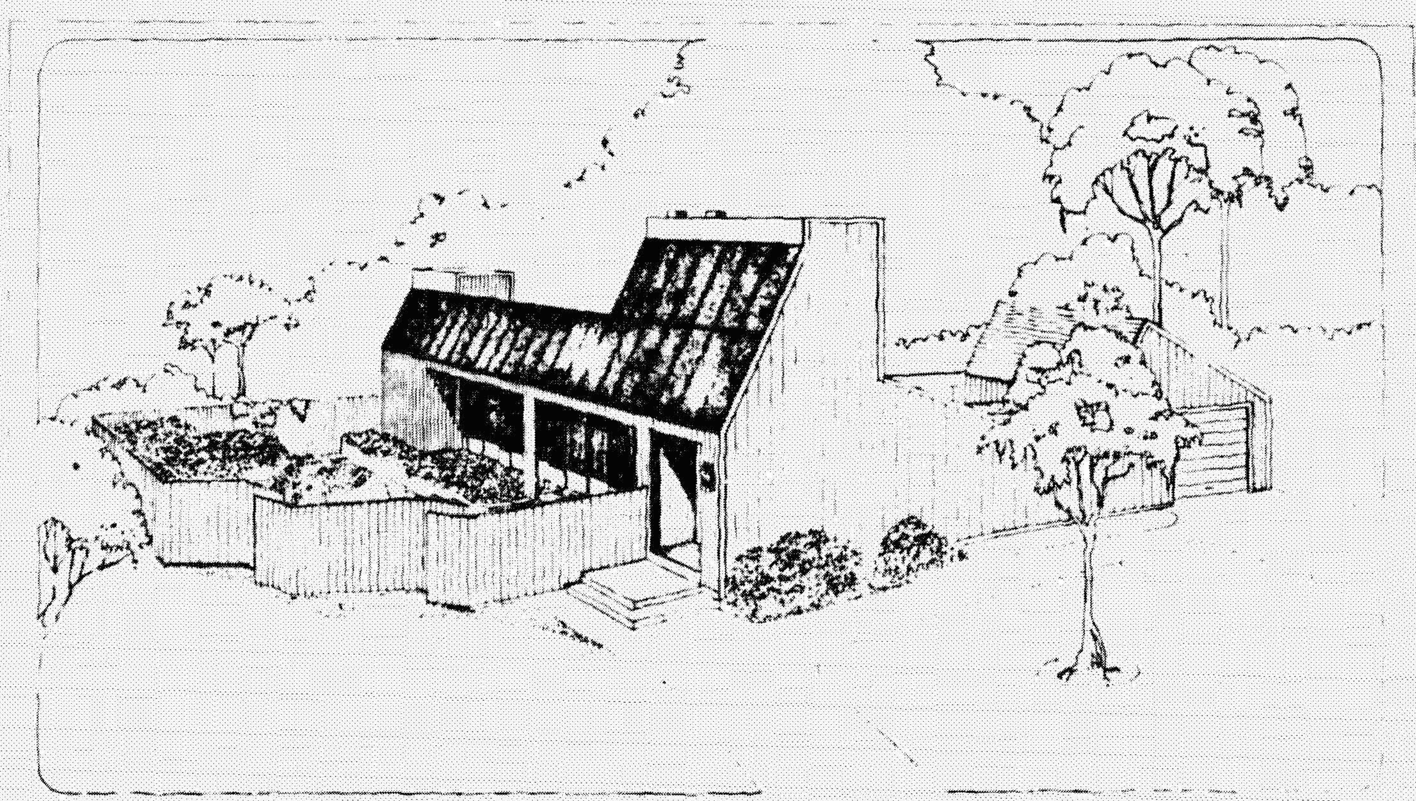
HG1D Perspective view from Southeast



CHAPTER 4

THERMAL ANALYSIS/COST STUDIES

The A/E design team analyzed various wall sections, ceiling and roof sections, windows and doors to determine which would be most cost effective for the Norfolk area.

Basic sections were chosen to provide a comparison. Each section studied was compared to the "base" both in terms of initial cost and thermal effectiveness. The "base" used was typical construction for 1974 electrically heated homes.

A component or assembly was deemed to be "cost-effective" if it satisfied the following test:

> "The added initial cost (through 20 year mortgage payments) of the assembly or component (or its estimated added initial cost by 1981) must be repaid to the buyer through energy or other savings effected by the assembly or component over the life of the mortgage."

For purposes of this cost-effectiveness study, a twenty year mortgage at an interest rate of 10% was assumed and an increase in energy costs of 10% per year was also assumed. A base cost of \$.05 per Kwh was used and, at the above rate of increase, resulted in an average cost of \$.143 per Kwh over the 20 year mortgage period.

For example:

Assume wall assembly A costs \$114.00 more to build than the base wall section but saves an average of \$63.00 per year in energy cost. It would cost the buyer of the house about \$13.30 per year to borrow that \$114.00. The net savings to the owner is therefore \$49.70 per year, over the life of the mortgage.

For these purposes the life-cycle of the residence is assumed to be twenty years although in fact it would probably be more.

It is interesting to note, in the example above, that in the first year the net \$ savings for wall section A is only about \$8.70 while in the last year of the mortgage (because of the 10% per year fuel cost increase) the energy saving would be about \$121.70. Over the twenty year mortgage term the owner would have saved approximately \$994.00 net.

This serves to illustrate that most energy conserving assemblies and components (purchased at today's prices) will save the same amount of energy tomorrow as they do today, but at much greater dollar savings to the owner.

COMPONENT/ASSEMBLY SELECTION

Based on the Component and Assembly Cost Effectiveness Study (see Appendix I), the following selections were made:

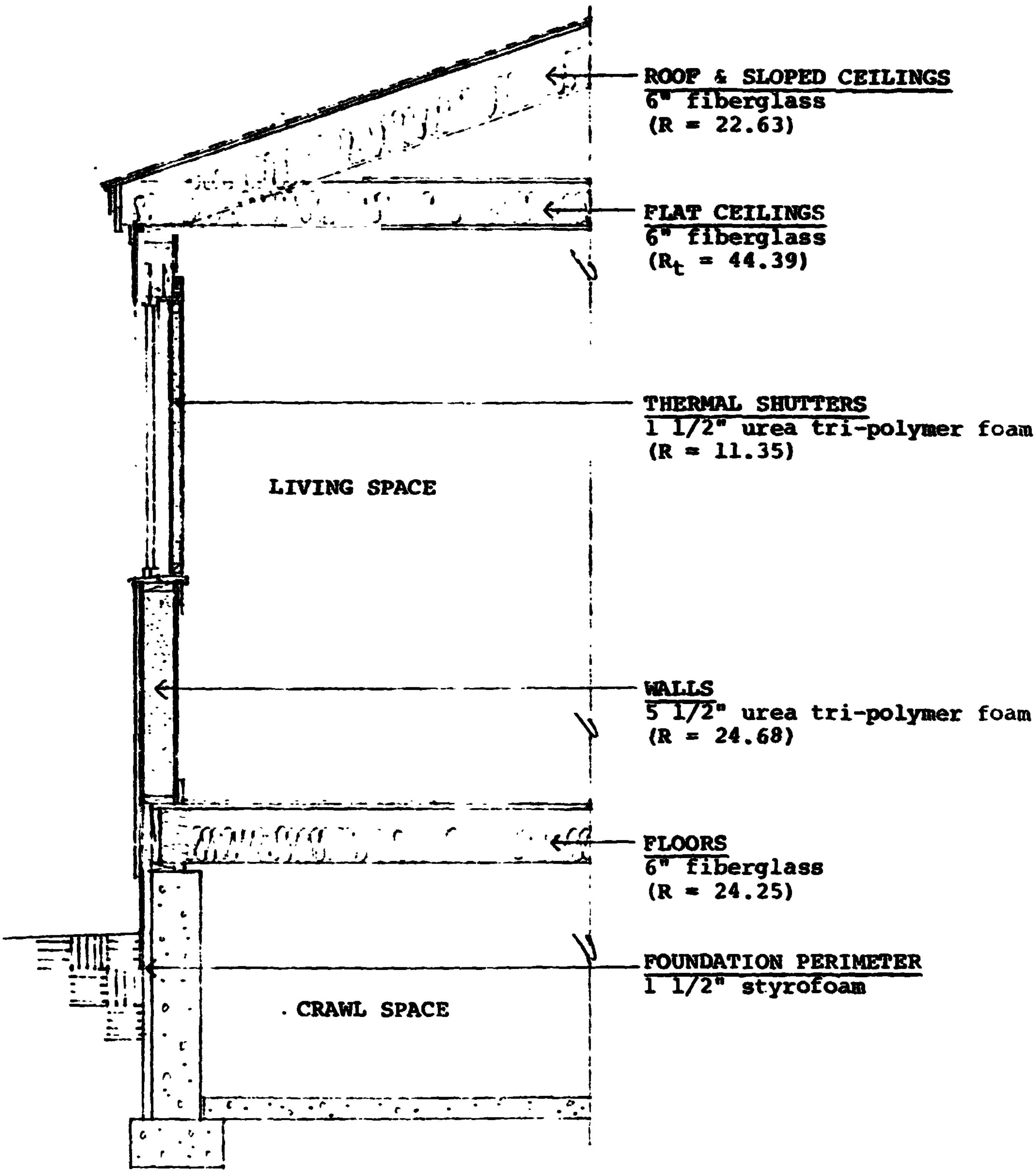
WALLS:	2 x 6 wood stud with 5 1/2" urea tri-polymer foam insulation, R=24.68
FLAT CEILINGS:	6" fiberglass insulation @ceilings and 6" fiberglass insulation @roof, R = 44.39
SLOPED CEILINGS:	6" fiberglass insulation (base selected), R = 22.63
FLOORS:	6" fiberglass insulation (base selected), R = 24.25
THERMAL SHUTTERS:	1 1/2" urea tri-polymer foam in wood and masonite frame, weatherstripped, R = 11.35

ENTRY DOORS:	Therma-Tru - with magnetic seal		
PATIO DOORS:	Aluminum with thermal break and insulating glass		
	Reynolds	u = .65	I=.08 CFM/SF
WINDOWS:	Aluminum with thermal break design and insulating glass		
	Alcoa, rolling	u = .57	I=.23 CFM/lfc
	Wood with triple glazing or equivalent, storm and insulating glass		
	Andersen(sliding)	u = .53,.33	I=.25 CFM/lfc

These components/assembly selections and their anticipated costs and savings (see Appendix I) are specific to the Norfolk, Virginia climatic conditions and to the specific siting configuration, and mechanical design of HG1D.

The house used as a basis of comparison is assumed to have R=13 fiberglass in the walls, R=22 fiberglass in the ceiling and first floor, and insulating glass in patio doors and windows. This is a very well insulated house by 1974 standards. The effect of this high base standard of insulation on the study was to demonstrate that additional insulation conforming to or exceeding this level of cost effectiveness and total energy savings is economically feasible now.

Proposed Construction Assembly



CHAPTER 5

SOLAR HEATING AND COOLING SYSTEMS

The NASA team has proposed a solar heating and cooling system using flat plate liquid collectors, nighttime radiator and water heat storage.

An electric powered heat pump is used to transfer heat (or cold) between the storage and the heated space of the house.

The A/E design team has estimated that approximately 320 square feet of flat plate collector area can supply virtually all of the requirements for space heating and domestic hot water of HG1D.

One of the purposes of HG1D is to provide NASA with a specific house design which can be used in a computer model for analysis of the heating and cooling system. It is expected that the characteristics of HG1D, weather bureau data and the characteristics of the heating system can be analyzed to determine the final system configuration.

The A/E design team has several recommendations for the heating and cooling system:

NASA HEATING AND COOLING SYSTEM

A/E design team recommendations:

1. On the occasions when natural heat gain through south windows (Sept. to April) exceeds the heating requirement of the house, the system should be able to cool the house and transfer the extracted heat to storage.

2. Summer design temperature should be maintained no lower than 75 degrees F.

3. Winter design temperature should be maintained no higher than 68 degrees F. during the day and 65 degrees between midnight and 6 AM.

4. Relative humidity control is an important comfort factor in both summer and winter and should be maintained at about 60%.

5. Cost effectiveness studies should be made comparing the system with a conventional air to air heat pump system and heat and conventional air conditioning system.

6. Studies will probably show that the water well system is not cost effective but the A/E believes this aspect should be tested and analyzed.

7. Heating zones in the house should be kept to a minimum for ease of operation.

8. Door closers should be installed on exterior doors and on doors between living room and hallway.

9. Primary air returns should be located in hallway near bathroom and at highest part of living room ceiling.

10. If possible, a variable speed fan motor should be used in the house air handler to control duct air velocity when all but one zone damper is closed.

11. The solar collector array should allow for future enlargement. HG1C provides space for a maximum of 525 gross sq.ft. of collectors (approx. 500 sq.ft. net).

12. Solar collector absorbers should be constructed of copper to provide longest life cycle and greatest corrosion resistance.

13. Solar collectors chosen for use should be protected against freezing or "meltdown", (recommended types are: PPG, Sunworks or Revere) and should be chosen based on performance and guarantee.

14. Heat storage tank should be chosen for cost and resistance to corrosion. (concrete, fiberglass, etc.)

15. Careful infiltration/exfiltration control by tight sealing of construction is important.

16. Recovery of heat from exhausted ventilation air would be highly desirable.

NASA team initial project goals

ENERGY/WATER GOALS
*(ANNUAL)

ENERGY CONSUMPTION:		CONTEMPORARY HOUSE (KW-HR)	PROJECT TECH HOUSE (KW-HR)
CENTRAL HEATING		29,300	6,000
CENTRAL AIR CONDITIONING		3,600	2,100
HOT WATER HEATING		4,380	1,500
LIGHTS		2,000	1,000
RANGE		1,175	600
REFRIGERATOR/FREEZER		1,830	1,200
CLOTHES DRYER		993	400
COLOR TV		500	250
FURNACE FAN		394	440
DISHWASHER		363	200
CLOTHES WASHER		103	90
IRON		144	130
COFFEE MAKER		106	90
MISC.		1,112	1,000
	TOTAL	46,000	15,000

**WATER CONSUMPTION:		CONTEMPORARY HOUSE (GALS.)	PROJECT TECH HOUSE (GALS.)
BATHING		22,265	16,480
DISHWASHING		2,920	2,190
LAUNDRY		5,840	5,840
CLEANING		2,190	2,190
TOILET		32,485	0
MISC.		7,300	7,300
	TOTAL	73,000	34,000

* FAMILY OF FOUR

** DOES NOT INCLUDE LAWN WATERING

CHAPTER 6

HEAT LOSS CALCULATIONS AND 20 YEAR HEATING-COOLING REQUIREMENTS

Estimating the life cycle savings of energy conserving components is a difficult matter for several reasons:

1. Initial assumptions about fuel cost increases must be made
2. Weather and temperature conditions vary from year to year
3. Occupant lifestyles strongly influence energy consumption
4. Building and HVAC systems must be designed concurrently
5. All components have different rates of "pay back"
6. Each component affects every other component.

The A/E design team has prepared designs and comparisons which can act as the basis for a NASA computer program to analyze or model the design in a more detailed manner during the final design phase.

The Study design HG1D was compared with a "base" house of the same configuration but without energy conserving components. The comparison was made for two purposes:

A. To show the difference in life-cycle heating energy costs between the "base" house and HG1D assuming a heat pump warm air heating system is used in both.
B. To determine what additional amount could be invested in a solar heating heat-pump system to provide 100% of annual heating, cooling and hot water requirements.

The latter is essentially a comparison of HG1D with normal heat pump and HG1D with solar/heat pump system.

Note: A summary of the results of this study appear at the end of this chapter. Detailed heat loss and energy requirement calculations are contained in Appendix II.

HEATING the "BASE" HOUSE Annual requirement 8862 Kwh/yr.

20 year heating requirement = 177,240 Kwh

ASSUMPTIONS:

Normal 1974 insulation for electric heat

Non "thermal break" windows and sliding doors

Normal vapor barrier and infiltration

No recapture of heat from exhausted air

No recapture of heat from passive systems

Air to Air heat pump (C.O.P. = 2.0)

25% of actual insolation heat gain is usable

Electric hot water heater

Fuel cost increases and mortgage rates described in Chapter 4

Base house 20 year heating cost $25,343.

HEATING HG1D HOUSE Annual requirement 3097 Kwh

20 year heating requirement = 61,940 Kwh

ASSUMPTIONS:

Increased insulation as proposed

Thermal break windows and sliding doors

Improved vapor barrier and infiltration control

Recapture 33% of heat from exhausted air

Recapture heat from passive systems

Air to Air heat pump (C.O.P. = 2.0)

50% of actual insolation heat gain is usable

Electric hot water heater

Fuel cost increases and mortgage rates described in Chapter 4

20 year heating cost $8857.

The difference between the two analyses above translates into a life-cycle savings of $16,488 in heating cost alone resulting from the addition of the energy conserving components (exclusive of the solar heating/heat pump system).

In order to determine the additional investment which could be justified for the solar heating/heat pump system (the cooling portion of the analysis and hot water heating are figured separately) the following approach was used:

HEATING

1. The total 20 year cost of heating HG1D is $8,857 as described above.

2. The total 20 year cost of operating the solar heating/heat pump system to provide 100% of the total space heating requirement is estimated to be $3,729. This figure assumes a Coefficient of Performance for the solar heating/heat pump system of 4.75.

3. The difference between 1 and 2 above is $5,128 which is the total fuel savings over 20 years which would result from the use of the solar heating/heat pump system instead of the conventional air to air heat pump.

4. Based on the above totals, if a home buyer could borrow $2,203. to finance the additional cost of the solar heating/heat pump system, his mortgage payments over the 20 year period would equal the fuel cost savings of $5,128.

COOLING

The NASA team has estimated that a contemporary house of 1500 sq. ft. would use 3600 Kwh annually for central air conditioning.

In order to determine the initial investment which could be justified for the nighttime radiator/heat pump cooling portion of the HVAC system, the following approach was used:

1. The A/E design team estimates that as a result of the energy conserving construction of HG1D, the annual energy requirement for cooling would be approximately 3000 Kwh using an air to air heat pump. (C.O.P. = 2.0)

2. If the C.O.P. of the proposed nighttime radiator/heat pump is 4.75 the total energy requirement over the 20 year period would be 60,000 Kwh or $8,580.

3. The difference between 1 and 2 above is $4,967 which is the total fuel savings over 20 years resulting from the use of the nighttime radiator/heat pump portion of the HVAC system instead of an air to air central system.

4. If a homebuyer could borrow $2,134 to finance the additional cost of the nighttime radiator/heat pump, his additional mortgage payments over 20 years would be $4,967. (Equal to the total fuel savings.)

DOMESTIC HOT WATER

The NASA team has estimated that a typical contemporary house uses 4380 Kwh/year for heating domestic hot water.

In order to determine the additional investment which could be justified for the solar heated hot water portion of the mechanical system, the following approach was used:

1. The A/E design team estimates that through the recapture of some heat from the waste water system and other conservation measures, the HG1D house hot water system might use 4160 Kwh/year if heated by an electric resistance hot water heater.

   The total energy requirement over the 20 year period would be 83,200 Kwh or $11,898.

2. Assuming that the solar hot water system can provide 80% of the requirement at virtually no energy cost and the balance from the heat pump system at a C.O.P. of 4.75, the annual energy requirement would be about 175 Kwh.

   The total energy requirement over the 20 year period would be 3500 Kwh or $500.

3. The difference between 1 and 2 above is $11,398 which is the total fuel saving over 20 years which would result from the use of a solar heated domestic hot water supply instead of an electric hot water heater.

4. Maintenance and replacement costs would be approximately equal.

5. If the home buyer could borrow $4900 to finance the additional cost of the solar heated hot water system, his mortgage payments over the 20 year period would be $11,354 (almost equal to the cost savings.)

CONCLUSIONS

Total Energy Costs Over 20 Year Period for HVAC and Domestic Hot Water

	HEATING	COOLING	HOT WATER	TOTALS
Base House	$25,345	$10,296	$12,527	$48,168
HG1D w/ conventional system	$ 8,857	$ 8,580	$11,898	$29,335
HG1D w/solar collectors/ night rad. & heat pumps	$ 3,729	$ 3,613	$ 500	$ 7,842

Note: A 10% per year fuel cost increase starting with $.05 per Kwh in 1975, (thus an average cost of $.143 per Kwh over the 20 year period) was used.

Difference in energy cost between HG1D with conventional HVAC and hot water systems and HG1D with solar heating/nighttime radiator/ heat pump system is:

$21,493.

The A/E design team estimates the additional cost of the proposed solar heat/nighttime radiator/heat pump/solar hot water system would be approximately:

$5,000. if mass produced

Total payments on a $5,000 mortgage (20 years at 10% per year) are:

$11,582.

Result: A net savings of $9,911. over 20 years.

Note: The "break even" investment in solar heating, cooling and hot water (where total mortgage payments equal total energy cost savings) is approximately:

$9,232.

This is the maximum investment in addition to the cost of a conventional system if the system is to be paid off in exactly 20 years.

Any initial investment less than $9,232 would result in a cost saving to the owner and/or a shortening of the payback time.

CHAPTER 7

EFFECT OF ENERGY CONSERVATION ON OCCUPANT LIFESTYLE

Studies have shown wide variation in energy consumption of families living in nearly identical residences . The reasons appear to lie in the attitudes of the occupants, their education about energy use, and lifestyle.

Recommendations:

1. The simplest possible system of controls for heating and cooling are recommended and even these should be as automatic as possible.

2. Education of the occupants in the techniques of energy conservation is important.

3. NASA expertise in the field of data gathering, processing and display could be effectively used in Project TECH to inform the occupants where and when most energy is used. A digital display panel at the desk in the kitchen area could provide information on energy demand and daily, monthly, yearly seasonal totals of kilowatt hours used and dollars expended on energy. (This would be particularly effective as a display when the house is open to the public). It is expected that by providing the occupants with up to date information, a change in attitude toward energy use would develop.

4. The A/E design team recommends incentives toward energy conservation rather than "control" wherever possible.

5. The use of doors between the sleeping area and living area are recommended for better zone temperature control.

CHAPTER 8

WASTE WATER RECLAMATION

The NASA team has designed a waste water partial reclamation system which when combined with other water saving strategies, should reduce water consumption by more than 50%. The system would also reduce requirements of sewerage system.

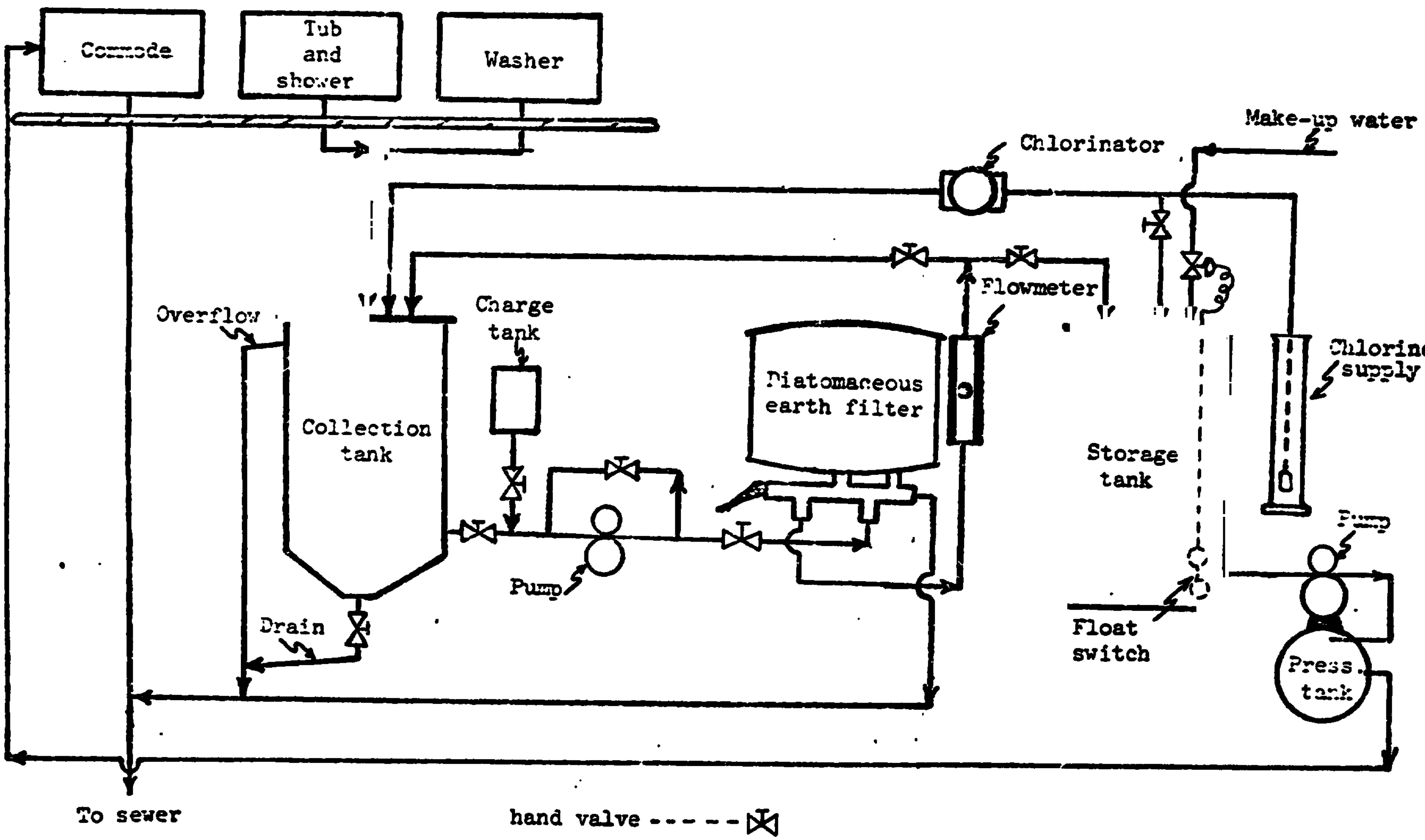
The system is to be located in the 3' high crawl space of the house as close as possible to bathrooms. Waste water from sinks, bathtubs, dishwashers and laundry will be collected, chlorinated, filtered and recycled for use as toilet flushing water. Waste from toilets will go directly to sewer.

The A/E design team recommends the use of this system in the Project TECH house in order to refine the design and obtain data on cost and on water saving capability in actual use.

There are several possible disadvantages to the system which should be evaluated during testing:

1. High initial cost vs. savings.
2. Space requirement.
3. Maintenance by owner(monthly draining or clean out).
4. Electrically driven pump (energy required)(operation during power outage).
5. Care must be taken to make sure there is no back up of waste water into fresh water supply.

WASTE WATER SYSTEM



CHAPTER 9

APPLIANCE CONTRIBUTION TO ANNUAL HEAT REQUIREMENT
APPLIANCE RECOMMENDATIONS

All heat producing appliances normally contribute to heat within the residence unless vented to the outside. This is advantageous in winter but counter-productive in summer. An attempt is made in the TECH house to utilize or vent heat as necessary.

Since heat from appliances cannot be counted on at any specific time it is not considered when sizing HVAC equipment. Several strategies were considered to make the best use of this energy.

1. Wall ovens can be vented (by convection) to outdoors in summer and to interior spaces in winter. A manual damper is required but little or no structural change is necessary. This strategy is recommended.

2. Rejected heat from refrigerator/freezer can be utilized or vented as above. This strategy is recommended.

3. Surface cooking unit hood normally vents outside but a recirculating activated charcoal filter hood is available. A hood which can either be ducted outside or recirculated inside could be specially fabricated. However, the energy saved by this strategy would probably never equal the added initial cost and complexity. (Exhaust vent fans are not used often enough.) This strategy is not recommended for the TECH house.

4. Electric dryer normally exhausts moist heated air outside. If such air was retained within the house it might upset the humidity balance and cause condensation in wall or roof sections. Exhausting hot moist air into crawl space will probably cause condensation on foundation walls and plumbing pipes, and rotting of wood components. This strategy is not recommended although substantial heat is wasted by electric dryers.

5. An alternate to item 4 above is to use air type solar collectors to provide hot air to dryer when sun is shining. An indicator light could tell the occupant when adequate solar heated hot air was available for clothes drying or a sensor circuit could automatically shut off electric heat coils in dryer when hot air is available. Air type collectors are commercially available. This strategy is recommended. An air collector system of 60 sq.ft. plus ducting and installation would cost approximately $105 per year in mortgage payments for the extra initial investment of $900. It would save between $70 and $140 per year in energy assuming that 50% to 100% of all clothes drying was done on clear sunny days.

   The system could be considered marginally cost effective depending on use patterns.

RECOMMENDED APPLIANCES

In an attempt to find energy efficiency ratings of appliances,the A/E design team contacted Consumers Union and were referred to The Center for Consumer Product Technology at National Bureau of Standards. NBS referred us to the Association for Home Appliance Manufacturers where we learned that only refrigerators, freezers and room air conditioners are rated and labeled for energy efficiency at this time. Several manufacturers who claim energy efficient appliances are not participants in the AHAM listings.

Based on research and experience the A/E design team recommends:

Refrigerator/Freezer:	Amana or Philco "energy saver" models
Microwave oven:	Amana, Litton or Philco (countertop units)
Surface cooking unit:	GE, Sears, Westinghouse or equal
Conventional wall oven:	GE, Frigidaire, or equal (single oven)
Hot water dispenser:	Kitchenaid KHD-110
Clothes washer/dryer	Westinghouse LT100P-DE100 stacking units
Dishwasher	Kitchenaid KDI-17A (energy saver cycle)

CHAPTER 10

SUN ANGLES AND OVERHANGS

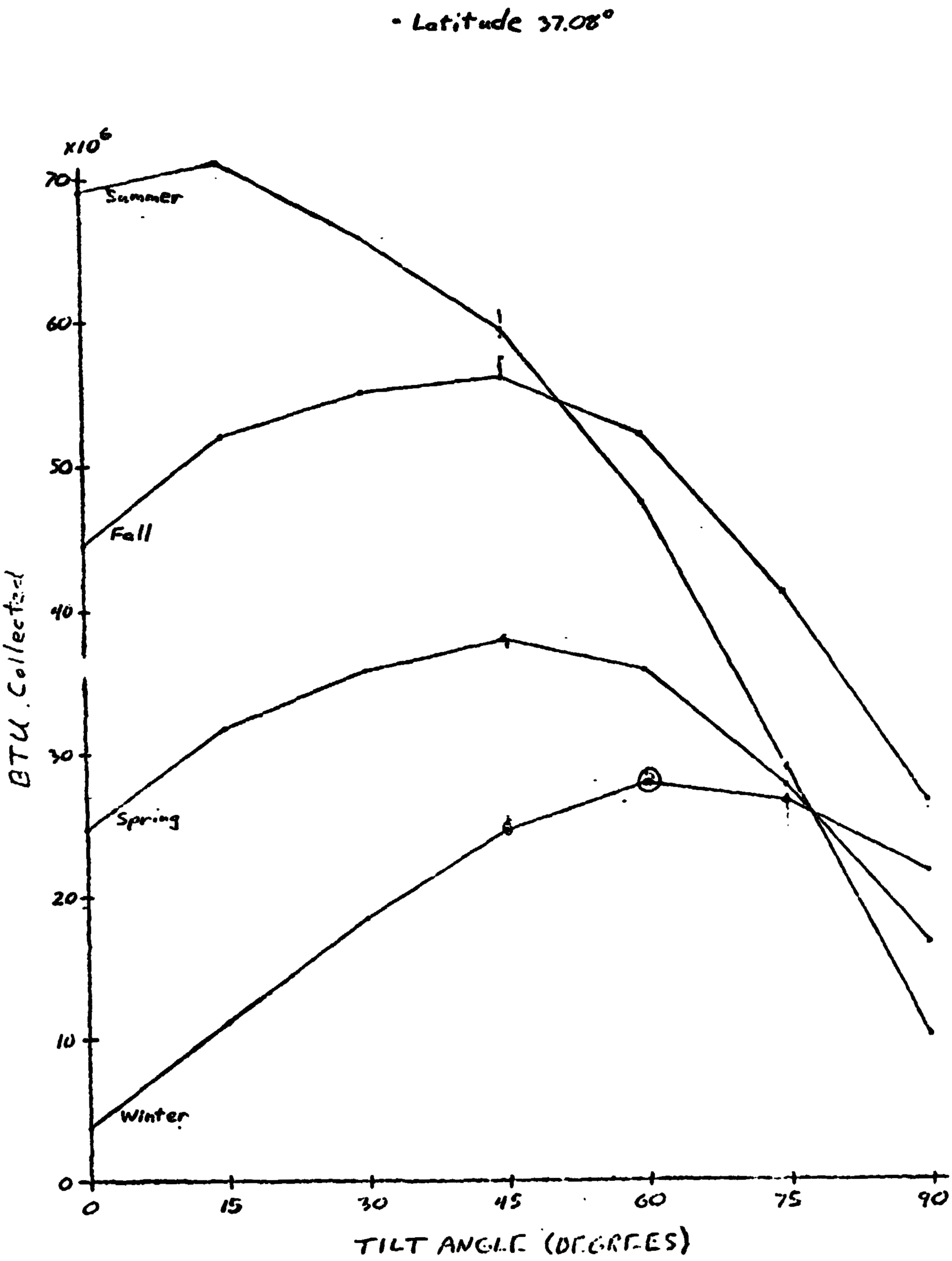
The NASA team determined the optimum tilt angle (from horizontal) of flat plate collectors for lattitude 37.08 degrees, to be 58 degrees. From this determinaticn (plus standard dimensions of flat plate collectors now available) the A/E design team determined the configuration of solar collectors if also used as a sun shading device. (Wherever possible it is economical to use one component for more than one function.)

Shading of south facing glass is critical to the proper use of glass area as a passive collector system. The heated part of the TECH house is a simple shed structure and the collectors themselves form the overhang necessary to generally exclude direct sunlight from south windows between March and September.

The overhang allows sun to enter the south windows between October and March, reaching a maximum penetration when the sun is lowest in the sky on December 21. This insolation contributes substantially to reducing the annual heating requirement but does not substantially increase the summer cooling load.

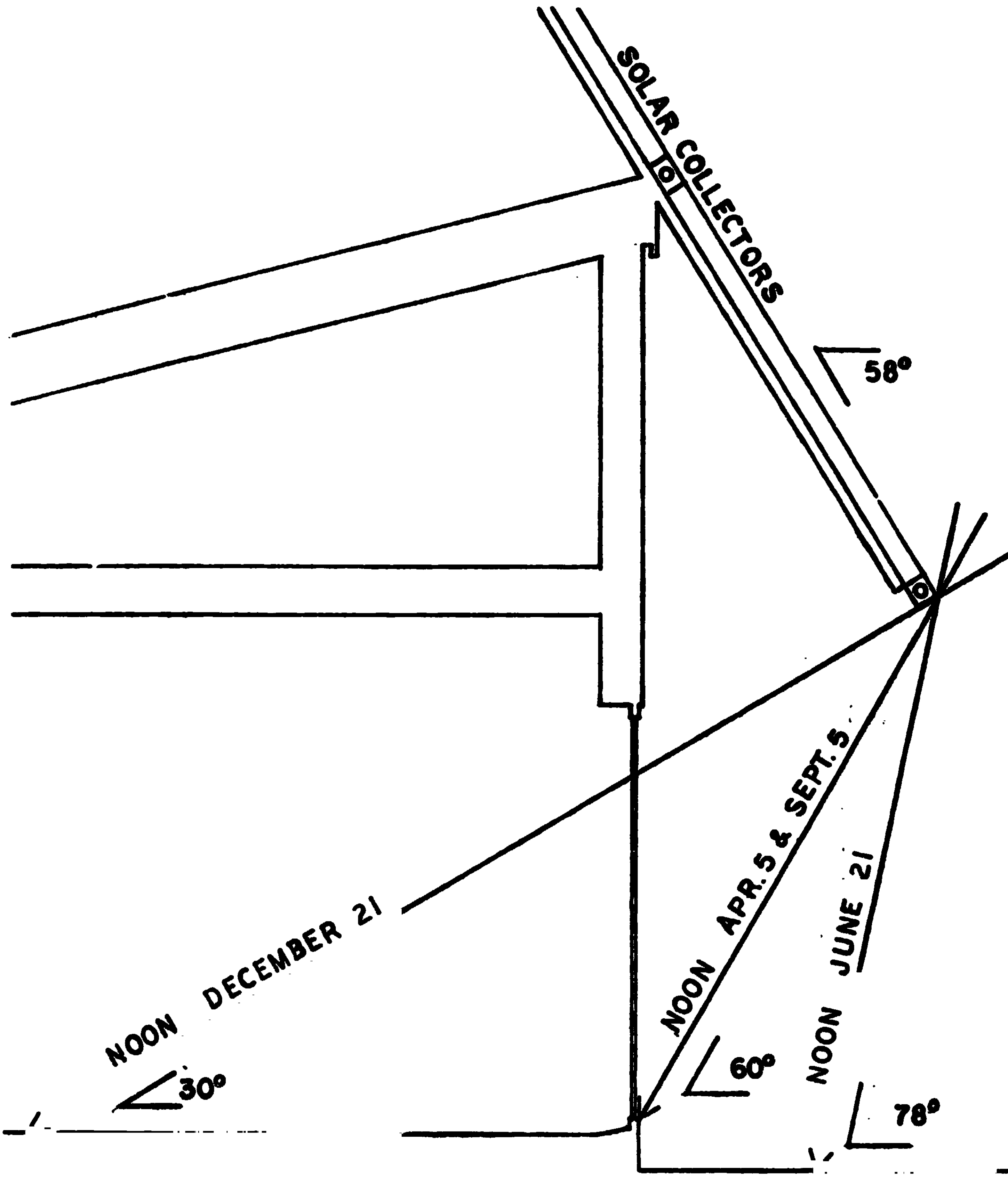
NASA Study of optimum tilt angles for Solar collectors at the Project TECH site.

APR 30 1975



SHADING OF SOUTH FACING GLASS

for 36° N Latitude



CHAPTER 11

SITING AND ORIENTATION

The project TECH site is well located for an energy conserving residence. The NOAA data for the Norfolk area shows a generally temperate macroclimate (a temperature of 0 degrees F has never been recorded in Norfolk). Prevailing winds are generally from the Southwest changing to Northeast in August and September and North-Northeast in February.

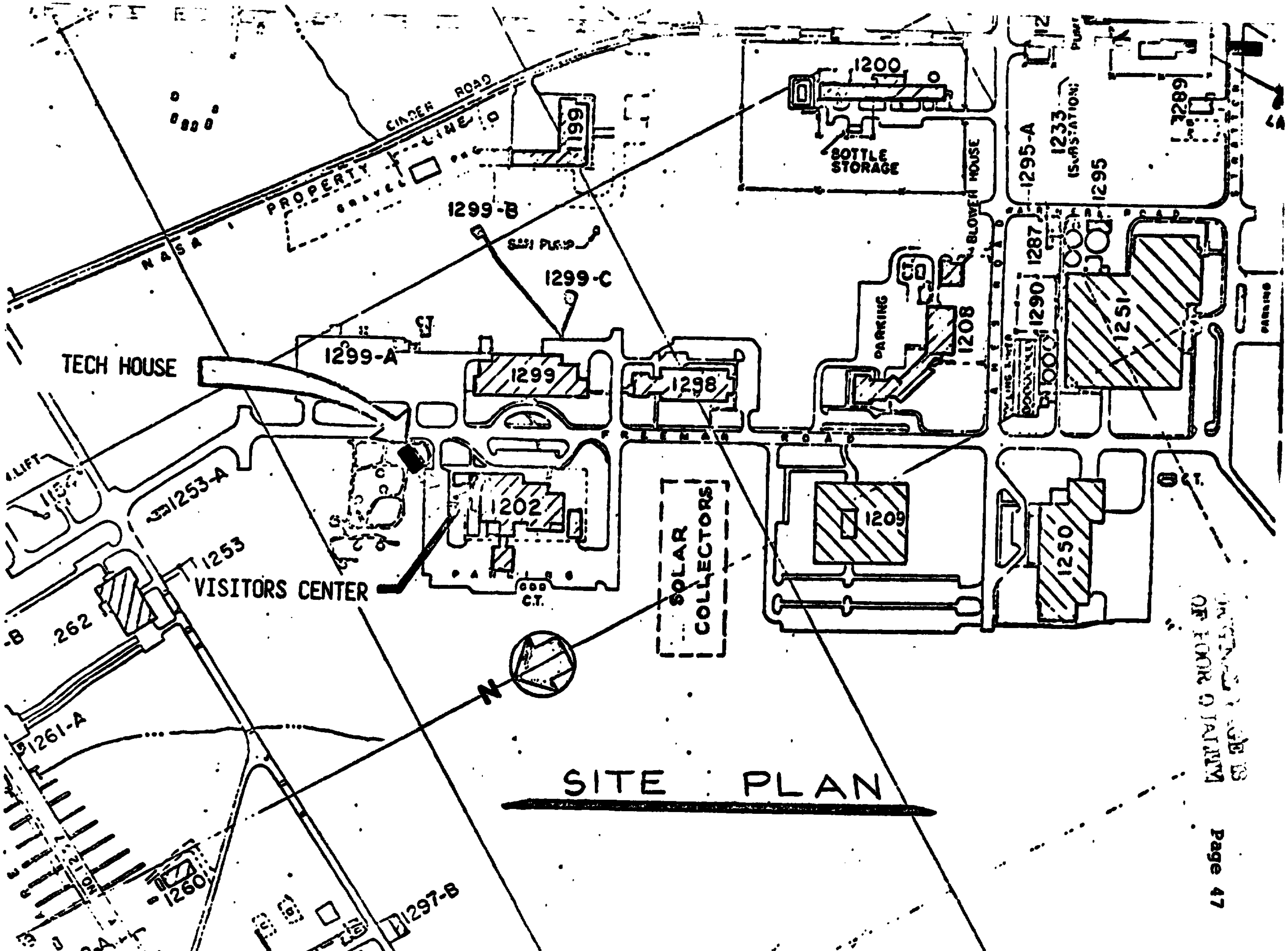
The specific house site is protected from cold winds by dense trees to the North and exposed to southeasterly summer breezes.

The best orientation for collection of solar heat is due south and there are no obstructions to full sun all day on the proposed site.

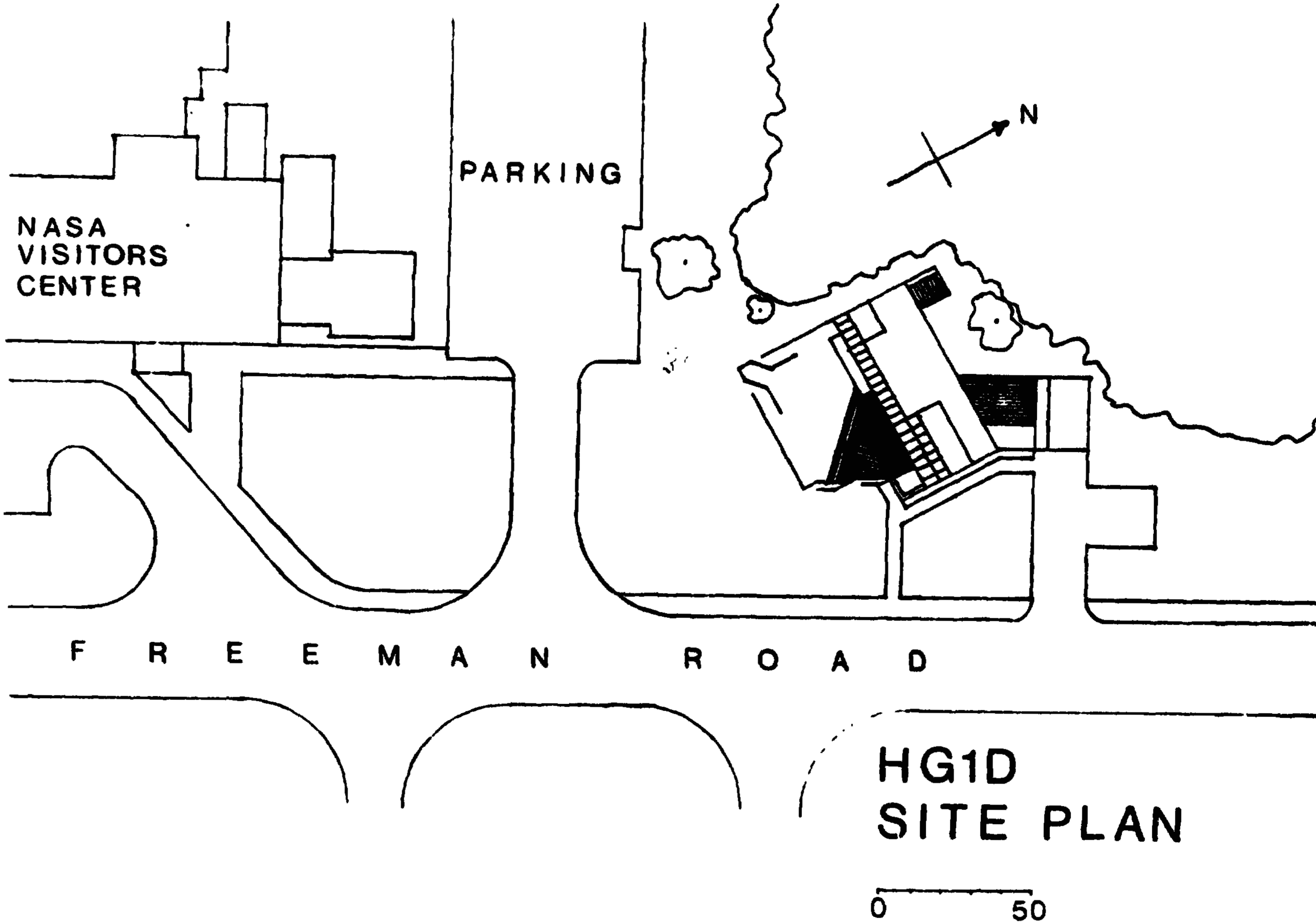
Access by visitors can be by sidewalk from the Visitors Center parking area. A fenced yard on the south side will be necessary to give privacy to the occupants. The fence is designed to allow air movement through it. The garage will have its driveway off Freeman Road.

The outdoor deck between the house and garage is sheltered from the Northeast wind by an unheated passage from the garage which serves as an airlock.

Ground water is 3' to 10' below grade depending on season, so a crawl space is proposed instead of a basement. The main floor of the residence will be approximately 2'-0" above existing grade in order to keep the bottom of the crawl space above ground water.



NASA PROPERTY LINE
CINDER ROAD
1200
BOTTLE STORAGE
BLOWER HOUSE
1199
1299-B
1299-C
TECH HOUSE
1299-A
1299
1298
FREEMAN ROAD
1202
VISITORS CENTER
C.T.
SOLAR COLLECTORS
1209
1208
PARKING
1295-A
1233
1295
1289
1287
1290
1251
1250
1253-A
1253
262
1261-A
1260
1297-B
N
SITE PLAN



HG1D
SITE PLAN

Local Climatological Data

Annual Summary With Comparative Data

1974

NORFOLK, VIRGINIA

p. 48

Narrative Climatological Summary

The city of Norfolk, Virginia, is located at Latitude 36° 51' North and Longitude 76° 17' West. It is almost surrounded by water, with Chesapeake Bay immediately to the north, Hampton Roads to the west, and the Atlantic Ocean only 18 miles to the east. It is traversed by numerous rivers and waterways and its average elevation above mean sea level is 13 feet. There are no nearby hilly areas and the land is low and level throughout the City. The climate, therefore, is necessarily a modification of the more desirable marine variety. The City's geographic position with respect to the principal storm tracks is especially favorable, being south of the average path of storms originating in the higher latitudes and north of the usual track of hurricanes and other tropical storms. These features combine to place Norfolk in one of the favored climatic regions of the world.

The winters are mild, while the autumn and spring seasons usually are delightful. Summers, though warm and long, frequently are tempered by cool periods, often associated with northeasterly winds off the Atlantic. Temperatures of 100° or higher are of very infrequent occurrence. Cold waves seldom penetrate to this area and during the period of continuous official record now available, a temperature of zero has never been recorded in Norfolk. Occasional winters pass without a measurable amount of snowfall. Most of Norfolk's snow generally occurs in light falls, which usually melts and disappears within 24 hours. Thus, from a climatological standpoint, Norfolk's weather is well suited for most outdoor activities at all seasons of the year.

From an agricultural standpoint, the Norfolk area, with its long frost-free period and prolonged growing season, averaging 244 days, is exceptionally well favored. The average date of the last freezing temperature in the spring is March 22, while the average date of the first in autumn is November 21. The average annual amount of rainfall is about 45 inches and considerably more than one-half of it falls in well distributed amounts during the crop growing season, April to October, inclusive, a fact of great importance to agricultural interests, which together with the light, warm, sandy soil of this section, makes it an area of unusual productive capacity, yielding bountiful supplies of various truck crops.

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA SERVICE / NATIONAL CLIMATIC CENTER ASHEVILLE, N.C.

Meteorological Data For The Current Year

Station: NORFOLK, VIRGINIA NORFOLK REGIONAL AIRPORT Standard time used: EASTERN Latitude: 36° 54' N Longitude: 76° 12' W Elevation (ground): 26 feet Year: 1976

Month	Temperature °F Averages Daily maximum	Daily minimum	Monthly	Extremes Highest	Date	Lowest	Date	Degree days Base 65 °F Heating	Cooling	Precipitation in inches Water equivalent Total	Greatest in 24 hrs.	Date	Snow, Ice pellets Total	Greatest in 24 hrs.	Date	Relative humidity pct. Hour 01	Hour 07	Hour 13	Hour 19	Wind Resultant Direction	Speed m.p.h.	Average speed m.p.h.	Fastest mile Speed m.p.h.	Direction	Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility 1/4 mile or less	Temperature °F Maximum (b) 90° and above	Maximum 32° and below	Minimum 32° and below	Minimum 0° and below	Average station pressure mb. Elev. 30 feet m.s.l.
JAN	50.4	40.7	48.6	79	27	20	13	934	3	3.32	0.80	21	T	T	12	78	81	68	73	33	1.6	11.2	29	24	31		8.2	3	8	23	13	0	1	6	0	1	3	0	1020.5
FEB	52.2	34.5	43.4	70	22	23	27	599	0	2.90	1.31	16-17	0.9	0.9	6	65	86	52	57	32	3.8	12.9	37	20	22	58	6.0	10	6	12	9	0	0	0	0	0	11	0	1016.9
MAR	62.0	43.0	53.1	84	7	29	15	377	10	5.16	1.32	29-30	7.5	7.5	25	66	88	52	58	32	2.0	12.9	35	22	21	60	6.8	8	10	13	12	2	1	1	0	0	2	0	1014.9
APR	72.1	49.6	60.8	92	29	35	7	183	64	3.34	1.94	4-5	0.0	0.0		67	88	41	52	24	4.1	12.1	32	29	4	73	9.4	10	9	11	10	0	2	0	1	0	0	0	1010.6
MAY	75.9	58.0	66.8	92	17	42	8	43	179	3.74	1.29	26-27	0.0	0.0		82	77	38	69	18	0.4	10.8	29	04	27		9.8	10	10	11	12	0	9	2	1	0	0	0	1014.2
JUN	80.6	65.0	72.8	94	20	54	4	0	244	4.70	1.22	23-24	0.0	0.0		86	84	63	74	04	2.3	10.7	39	07	20		7.0	4	9	17	12	0	6	2	4	0	0	0	1013.5
JUL	87.4	69.2	78.3	97	15	60	23	0	419	5.47	3.01	26	0.0	0.0		80	79	55	64	25	2.6	8.9	37	22	9	83	5.1	10	10	11	6	0	6	0	10	0	0	0	1015.6
AUG	84.2	70.5	77.4	93	28	59	12	0	390	8.33	2.47	5-6	0.0	0.0		92	90	71	83	18	2.0	8.7	31	35	17	66	7.0	2	19	10	15	0	12	0	9	0	0	0	1017.6
SEP	78.7	64.0	71.4	92	13	52	20	10	212	4.40	2.19	6-7	0.0	0.0		86	84	66	77	04	1.0	10.0	25	03	29	58	6.0	8	11	11	13	0	4	2	5	0	0	0	1016.6
OCT	68.7	48.6	58.7	84	15	34	22	219	20	1.23	0.90	15-16	0.0	0.0		79	82	52	70	36	2.8	9.1	26	01	7		4.2	16	8	7	7	0	2	1	0	0	0	0	1022.6
NOV	62.7	44.5	53.5	84	1	29	27	571	32	1.22	0.47	25	0.0	0.0		70	71	68	8.	26	3.7	10.0	28	30	25		6.3	17	4	9	6	0	1	3	0	0	5	0	1017.6
DEC	54.4	37.9	46.0	71	25	27	11	904	0	3.8	1.07	1-2	T	T	19	81	84	63	73	28	3.7	11.3	31	14	1		6.4	9	9	17	11	0	1	2	0	0	8	0	1016.0
YEAR	69.6	52.1	60.9	97	JUL 15	22	FEB 27	2910	1931	47.90	3.01	JUL 26	8.4	7.5	MAR 25	77	78	57	68	30	1.3	10.7	37	29	FEB 22		6.1	105	100	160	110	1	38	26	24	3	27	0	1016.7

Normals, Means, And Extremes

Month	Temperatures °F Normal Daily maximum	Daily minimum	Monthly	Extremes Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F Heating	Cooling	Precipitation in inches Water equivalent Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets Maximum monthly	Year	Maximum in 24 hrs.	Year
(a)				26		26					26		26		26		26		26	
J	48.8	32.2	40.5	78	1975	8	1972	760	0	3.39	6.40	1958	1.00	1949	3.80	1967	14.2	1966	9.1	1973
F	50.0	32.7	41.4	78	1972	8	1965	661	0	3.31	5.72	1956	0.6	1955	1.87	1970	7.5	1969	6.3	1963
M	57.3	38.9	48.1	85	1968	20	1950	532	0	3.42	6.01	1958	1.5	1967	3.10	1958	7.9	1960	7.5	1970
A	67.7	47.9	57.8	97	1960	28	1964	226	10	2.71	5.80	1953	1.29	1963	2.40	1953	1.2	1964	1.2	1964
M	76.2	57.2	66.7	97	1956	38	1966	53	106	3.34	7.77	1961	1.48	1965	2.94	1961	0.0		0.0	
J	83.5	65.5	74.5	101	1964	45	1967	0	285	3.62	9.72	1963	0.37	1954	6.89	1963	0.0		0.0	
J	86.8	69.9	78.3	103	1952	56	1972	0	412	5.70	12.83	1950	1.69	1961	5.04	1969	0.0		0.0	
A	84.9	68.9	76.9	99	1968	52	1965	0	369	5.92	11.19	1967	1.60	1972	11.40	1964	0.0		0.0	
S	79.6	63.9	71.8	98	1954	45	1967	9	213	4.20	12.26	1964	0.36	1958	6.79	1959	0.0		0.0	
O	70.1	53.3	61.7	95	1954	29	1965	141	38	3.06	10.12	1971	0.93	1967	4.38	1971	0.0		0.0	
N	60.5	42.6	51.6	86	1974	20	1950	402	0	2.94	7.01	1951	0.49	1965	3.39	1952	0.6	1950	0.6	1950
D	50.8	34.0	42.3	79	1971	14	1962	704	0	3.11	8.03	1973	1.08	1965	2.12	1958	14.7	1958	11.4	1958
YR	68.0	50.8	59.3	103	JUL 1952	8	JAN 1972	3488	1441	44.68	12.83	JUL 1950	0.36	SEP 1958	11.40	AUG 1964	14.7	DEC 1958	11.4	DEC 1958

Month	Relative humidity pct. Hour 01	Hour 07	Hour 13	Hour 19	Wind Mean speed m.p.h.	Prevailing direction	Fastest mile Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility 1/4 mile or less	Temperatures °F Max. (b) 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below	Average station pressure mb. Elev. 30 feet m.s.l.
(a)	26	26	26	26	26	19	21	21		19	26	26	26	26	26	26	26	26	26	26	26	26	2
J	73	75	60	68	11.7	SW	56	SW	1959	57	6.5	9	6	16	10	1	*	2	0	3	16	0	1019.7
F	72	74	57	66	12.1	NNE	66	SW	1969	58	6.2	8	6	14	10	1	1	3	0	1	14	0	1017.1
M	71	73	54	62	12.5	SW	57	W	1965	63	6.1	9	7	15	11	*	2	2	0	*	6	0	1015.6
A	73	74	51	62	11.6	SW	62	N	1956	66	5.9	8	10	12	10	*	3	2	*	0	*	0	1015.3
M	81	77	56	68	10.3	SW	53	SW	1965	67	6.1	8	10	13	10	0	5	2	1	0	0	0	1013.6
J	84	80	58	68	9.5	SW	52	W	1970	68	5.8	8	11	11	9	0	6	2	7	0	0	0	1014.7
J	85	82	60	72	9.0	SW	63	SW	1956	65	6.0	8	11	12	11	0	8	1	11	0	0	0	1015.6
A	87	85	63	76	8.7	SW	57	NE	1957	65	5.9	8	12	11	11	0	7	2	8	0	0	0	1017.0
S	85	84	62	76	9.7	NE	73	W	1960	64	5.7	9	10	11	8	0	3	2	3	0	0	0	1017.0
O	83	83	61	76	10.4	NE	70	S	1954	60	5.3	12	7	12	8	0	1	3	*	0	*	0	1020.0
N	76	79	55	69	10.7	SW	52	SE	1962	60	5.5	11	8	11	8	0	1	2	0	0	3	0	1018.0
D	73	76	59	69	11.1	SW	48	NW	1960	57	6.0	10	7	14	9	*	*	2	0	1	14	0	1017.1
YR	79	79	58	69	10.6	SW	78	S	OCT 1954	63	5.9	108	105	152	110	2	37	23	30	5	53	0	1016.7

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 105 in August 1918, lowest temperature 2 in February 1895; maximum monthly precipitation 15.61 in August 1942; minimum monthly precipitation 0.04 in October 1874; maximum monthly snowfall 18.6 in December 1892; maximum snowfall in 24 hours 17.7 in December 1892; fastest mile wind 80 W in June 1925.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

ORIGINAL PAGE IS OF POOR QUALITY

12 av 145 av 399 av 671 av 784 av 677 av 524 av

Average Temperature

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1935	39.9	41.8	36.9	54.7	65.0	75.9	78.2	77.4	71.4	62.8	55.6	37.8	59.5
1936	37.4	37.0	53.8	55.9	67.9	74.0	78.1	78.6	73.6	63.0	50.4	46.2	60.0
1937	51.8	41.8	46.9	57.0	67.6	76.6	78.4	78.6	69.9	59.6	51.2	42.1	60.3
1938	41.7	46.8	56.6	60.0	67.2	74.5	79.0	80.4	71.6	61.7	55.6	43.2	61.3
1939	43.7	49.8	52.4	59.8	67.8	77.7	77.3	78.3	76.8	60.3	50.0	44.4	61.0
1940	31.0	42.4	46.8	55.2	66.4	77.0	78.6	76.8	70.4	59.8	52.8	48.4	58.8
1941	40.4	38.0	44.8	60.6	69.6	74.8	79.1	78.2	73.0	68.8	55.9	47.4	61.0
1942	41.1	38.8	51.1	65.7	70.9	77.3	82.0	77.6	74.6	64.6	54.8	42.4	61.3
1943	43.3	44.6	49.0	55.1	70.3	80.0	79.1	78.6	70.8	60.2	51.9	42.8	60.4
1944	41.7	43.4	47.4	57.6	70.6	77.4	78.2	77.4	74.8	62.4	51.3	39.8	60.4
1945	37.8	44.0	59.5	62.1	66.4	77.1	76.4	77.1	76.7	62.9	56.2	38.4	61.2
1946	43.8	44.9	56.4	58.1	64.6	73.7	76.8	75.4	72.7	64.8	57.9	48.4	61.7
1947	49.0	37.0	42.8	59.0	66.6	73.7	77.0	78.8	74.9	67.4	51.4	43.8	60.2
1948	36.0	43.1	52.4	58.6	65.1	75.7	78.8	78.0	72.2	60.1	58.2	47.2	60.8
1949	49.8	50.0	50.9	58.8	67.2	79.8	81.7	78.0	71.9	66.7	52.0	47.5	62.7
1950	53.9	43.4	47.8	56.3	65.7	75.3	78.1	76.5	71.0	65.6	52.1	40.4	60.7
1951	43.9	44.7	48.8	58.8	66.6	75.6	79.6	78.3	73.2	63.3	49.7	48.2	61.2
#1952	46.0	45.3	49.1	60.0	68.2	79.8	82.0	79.2	73.9	60.1	53.9	44.7	61.9
1953	46.1	46.2	51.2	58.7	71.6	73.9	79.7	77.1	71.8	63.0	51.4	43.6	61.4
1954	41.7	46.7	48.7	60.8	64.0	75.6	78.0	77.9	73.8	64.6	50.0	41.3	60.3
1955	38.4	41.2	52.4	60.3	67.7	71.9	81.4	79.9	72.2	62.3	50.4	37.8	59.7
1956	37.2	45.9	48.1	56.0	64.3	75.3	76.7	77.3	70.8	63.9	51.1	52.2	60.1
1957	39.7	44.6	48.4	62.3	68.1	77.7	78.6	75.7	74.6	58.2	53.9	46.7	60.7
1958	37.1	36.4	43.6	57.8	64.7	71.8	81.7	77.8	70.7	61.4	55.6	37.2	58.2
#1959	39.7	43.	49.4	60.2	69.7	76.4	76.7	79.4	73.6	64.7	51.1	44.8	60.9
1960	41.7	41.4	39.9	63.7	68.3	75.9	77.8	80.0	72.4	61.8	52.7	36.5	59.3
1961	35.0	43.6	53.1	55.9	63.6	72.6	80.6	77.7	75.3	60.6	53.2	41.5	59.6
1962	38.9	41.0	43.7	58.4	68.0	73.6	75.2	76.6	69.1	61.8	49.8	37.2	57.6
1963	37.1	35.7	53.4	60.3	64.6	73.2	77.0	76.7	68.7	60.1	52.0	35.2	57.7
1964	42.2	38.9	49.9	55.2	66.4	74.5	77.3	74.4	70.8	57.7	54.6	46.5	59.1
1965	39.7	41.0	44.4	54.5	69.7	72.8	76.7	77.1	73.6	59.0	51.6	43.5	58.6
1966	35.8	38.6	47.9	50.9	63.6	71.6	78.0	76.8	69.1	59.1	50.9	41.4	57.1
1967	45.9	39.9	47.7	58.0	61.2	71.2	76.1	75.2	68.9	58.7	45.9	44.0	57.5
1968	34.8	34.0	50.0	55.1	64.6	74.9	78.0	80.5	71.9	61.1	52.9	41.4	58.4
1969	38.5	39.8	44.7	59.4	67.4	77.1	79.2	76.2	71.1	62.2	49.1	40.9	58.9
1970	33.9	39.2	44.7	58.7	67.5	74.9	76.9	78.0	74.7	63.7	51.7	47.0	59.1
1971	38.6	44.7	46.9	55.9	65.0	76.0	77.2	75.7	73.2	66.7	52.4	52.3	60.4
1972	46.4	43.2	49.0	58.4	63.9	70.5	77.6	75.8	71.9	59.2	51.4	49.2	59.5
1973	40.5	39.7	52.1	58.3	64.9	76.9	78.3	78.5	75.0	64.2	53.9	46.2	60.9
1974	48.6	43.4	53.1	60.8	66.8	72.8	78.1	77.4	71.4	58.7	53.9	46.0	60.9
REC MEAN	41.9	42.8	48.8	57.4	66.7	74.7	78.6	77.5	72.4	62.2	52.0	43.0	59.8
MAX	49.2	50.9	57.4	66.7	73.7	83.2	86.7	84.9	79.8	69.8	59.9	51.2	67.0
MIN	33.7	34.0	40.0	48.1	57.6	66.1	70.5	70.0	65.2	54.6	44.1	36.0	51.7

Heating Degree Days

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1954-55	0	0	4	149	442	727	820	662	388	171	98	7	3436
1955-56	0	0	0	122	433	837	854	566	517	280	121	8	3722
1956-57	0	0	21	69	422	590	778	564	588	173	99	1	2985
1957-58	0	0	9	214	329	594	652	795	655	242	44	7	3705
#1958-59	0	0	7	132	282	839	778	591	678	180	37	4	3364
1959-60	0	0	10	133	424	681	714	679	796	152	37	1	3566
1960-61	0	0	0	120	368	677	921	595	385	318	110	16	3729
1961-62	0	0	7	155	368	722	800	668	655	288	50	0	3718
1962-63	0	0	37	148	649	854	859	815	357	202	108	0	3829
1963-64	0	0	44	156	384	920	697	719	482	303	108	4	3817
1964-65	0	0	4	232	312	575	780	667	635	320	80	15	3560
1965-66	0	0	1	105	308	657	897	734	527	330	121	21	3867
1966-67	0	0	22	101	437	725	588	699	531	244	157	21	3817
1967-68	0	0	56	211	566	644	928	893	471	294	88	0	4138
1968-69	0	0	0	124	341	726	814	697	624	192	44	0	3582
1969-70	0	0	6	131	489	741	960	714	622	243	57	0	3963
1970-71	0	0	16	93	383	552	812	567	555	269	60	0	3326
1971-72	0	0	3	37	381	340	572	626	494	273	81	11	2869
1972-73	0	0	6	197	406	484	752	703	603	217	67	0	3215
1973-74	0	0	0	83	393	575	504	599	377	183	63	0	2787
~~1974-75~~	~~0~~	~~0~~	~~16~~	~~213~~	~~371~~	~~586~~							

3536 average

Cooling Degree Days

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1969	0	0	0	42	135	369	444	337	199	69	0	0	1587
1970	1	0	0	19	140	303	376	412	311	60	0	0	1622
1971	0	3	0	3	76	336	383	343	259	87	20	5	1518
1972	0	0	8	20	40	183	398	343	317	22	10	2	1343
1973	0	0	16	27	112	363	420	424	307	64	17	1	1751
1974	2	0	10	64	124	244	419	390	311	26	32	0	1331

Precipitation

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1935	3.10	3.53	4.17	5.22	2.69	1.81	7.00	3.03	5.29	0.78	3.64	2.25	44.09
1936	6.60	4.16	3.89	4.71	0.98	3.93	9.30	1.77	4.99	3.31	1.07	4.80	52.21
1937	6.46	2.35	3.08	6.46	3.35	3.49	3.09	6.77	4.93	2.08	5.37	1.87	59.76
1938	2.80	1.81	3.73	3.78	5.06	7.29	3.28	2.78	2.76	0.98	3.08	1.83	39.74
1939	3.95	3.52	5.40	4.26	1.33	6.11	12.60	6.20	0.36	5.04	3.14	1.13	55.44
1940	2.35	2.38	2.09	3.39	3.64	2.31	3.44	10.16	6.10	1.10	4.65	1.16	40.49
1941	2.12	2.56	2.50	0.73	0.94	4.31	4.32	4.99	2.09	2.37	1.57	2.87	36.81
1942	2.76	2.63	5.5-	0.73	2.70	1.23	1.61	15.01	2.63	3.07	0.96	3.15	47.60
1943	2.80	1.61	4.18	2.77	3.03	4.20	10.27	1.00	0.08	3.90	1.38	2.01	44.27
1944	4.47	5.90	6.97	2.57	0.89	1.24	1.43	3.55	9.61	3.45	4.08	2.43	49.25
1945	1.72	3.18	1.30	2.12	2.64	7.72	12.02	3.32	5.74	1.32	4.02	3.67	53.85
1946	3.27	3.70	1.60	3.42	4.50	4.36	7.24	2.31	5.96	1.26	3.95	1.31	45.66
1947	4.18	1.26	3.54	2.98	1.88	3.66	8.28	2.17	4.01	1.47	6.25	2.38	42.18
1948	4.38	3.63	2.82	4.84	9.98	4.66	4.13	3.15	2.24	2.41	5.51	4.09	51.59
1949	1.63	4.27	2.85	1.71	5.47	2.57	6.35	14.51	2.06	2.29	5.31	2.10	49.20
1950	2.11	1.09	2.79	3.55	2.27	3.07	10.79	2.85	2.09	1.95	1.92	2.86	36.39
1951	1.61	1.59	2.99	2.24	2.60	4.80	2.78	0.00	0.95	2.65	6.36	2.07	41.08
#1952	4.31	3.52	4.61	2.16	1.07	2.29	6.14	4.73	2.36	2.75	4.83	3.22	42.70
1953	1.73	3.40	2.07	3.80	5.18	2.92	3.36	9.18	6.17	1.03	2.44	4.35	43.10
1954	2.40	1.50	3.16	2.08	3.18	2.37	3.96	7.27	5.67	1.70	2.19	2.03	38.19
1955	2.41	2.71	3.96	1.75	1.58	2.47	3.34	6.18	9.26	1.40	2.09	2.14	45.20
1956	2.49	3.72	3.09	3.81	2.57	2.07	6.63	3.04	3.70	0.06	1.91	2.76	47.45
1957	4.11	4.76	4.06	1.80	1.96	3.56	2.18	3.96	7.10	3.44	6.81	4.53	48.37
1958	4.18	3.55	6.41	3.20	6.23	4.99	6.27	10.40	0.36	4.80	3.07	4.10	57.70
1959	1.52	1.04	3.96	3.03	1.98	2.40	7.49	2.81	10.75	0.78	1.85	2.05	51.13
1960	3.05	3.37	2.34	1.40	4.43	2.37	6.78	6.49	5.80	2.76	1.10	3.37	41.76
1961	3.52	4.56	3.89	2.76	7.79	3.68	6.70	1.69	7.42	4.12	1.20	3.76	46.67
1962	3.56	2.30	4.37	4.49	3.68	3.03	3.05	4.09	3.07	4.48	3.06	3.00	55.13
1963	3.36	3.75	2.94	1.29	1.53	9.72	2.01	2.40	6.84	1.21	5.31	2.65	43.27
1964	4.56	4.56	2.26	2.38	1.56	2.58	7.23	10.38	12.20	3.55	1.16	2.95	57.71
1965	2.73	2.59	2.03	2.24	1.44	4.09	3.46	3.00	0.77	1.29	0.49	1.08	26.67
1966	4.06	3.83	1.50	1.04	5.95	1.62	4.20	3.24	3.39	1.25	1.05	3.13	37.90
1967	3.46	3.50	1.34	1.31	3.25	1.57	7.21	11.19	3.02	0.83	1.75	4.20	43.21
1968	3.61	2.01	4.70	2.10	2.16	2.07	4.23	2.06	1.44	4.44	3.36	3.14	37.71
1969	2.24	2.10	3.88	2.07	2.07	4.13	12.70	5.20	2.72	1.18	2.77	3.71	48.33
1970	2.27	3.97	3.37	3.10	2.30	4.10	3.35	2.04	1.72	1.30	2.30	3.01	31.22
1971	4.03	3.50	3.88	2.10	4.00	2.10	4.81	4.63	5.40	10.12	0.97	1.46	47.73
1972	2.96	3.50	2.45	2.15	3.35	4.92	4.65	1.00	8.01	4.09	6.46	3.12	46.23
1973	3.36	3.21	4.09	3.40	3.02	3.92	6.19	7.60	0.86	1.37	1.90	5.83	47.30
1974	3.52	2.96	3.18	3.36	3.76	4.76	3.67	8.33	4.40	1.23	1.22	3.81	47.96
RECORD MEAN	3.29	3.35	3.71	3.19	3.66	4.08	5.72	3.40	3.09	3.12	2.97	3.21	45.17

Snowfall

Season	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Total
1935-36	0.0	0.0	0.0	0.0	T	10.2	0.3	13.2	T	0.0	0.0	0.0	27.7
1936-37	0.0	0.0	0.0	0.0	T	T	0.0	9.6	T	0.0	0.0	0.0	9.6
1937-38	0.0	0.0	0.0	0.0	0.0	0.1	0.7	T	0.0	0.0	0.0	0.0	0.8
1938-39	0.0	0.0	0.0	0.0	0.4	0.0	9.4	0.0	3.2	0.4	0.0	0.0	13.0
1939-40	0.0	0.0	0.0	0.0	0.0	3.3	12.7	1.8	4.6	1.7	0.0	0.0	22.9
1940-41	0.0	0.0	0.0	0.0	T	0.0	3.3	5.7	0.3	0.0	0.0	0.0	9.3
1941-42	0.0	0.0	0.0	0.0	0.0	0.0	2.4	T	0.0	0.0	0.0	0.0	2.4
1942-43	0.0	0.0	0.0	0.0	0.0	7.7	2.0	0.2	0.1	0.0	0.0	0.0	10.0
1943-44	0.0	0.0	0.0	0.0	T	1.1	4.7	T	T	T	0.0	0.0	5.8
1944-45	0.0	0.0	0.0	0.0	0.0	0.7	T	T	0.0	0.0	0.0	0.0	0.7
1945-46	0.0	0.0	0.0	0.0	T	3.2	4.4	T	0.0	0.0	0.0	0.0	7.6
1946-47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	10.0	0.0	0.0	0.0	13.0
1947-48	0.0	0.0	0.0	0.0	T	2.3	8.7	11.6	T	0.0	0.0	0.0	22.6
1948-49	0.0	0.0	0.0	0.0	0.0	1.2	0.4	0.0	T	0.0	0.0	0.0	1.6
1949-50	0.0	0.0	0.0	0.0	0.0	T	0.8	0.7	0.0	0.0	0.0	0.0	1.5
1950-51	0.0	0.0	0.0	0.0	0.4	T	0.0	2.7	T	0.0	T	T	3.0
1951-52	0.0	0.0	0.0	0.0	T	T	T	1.0	T	0.0	0.0	0.0	1.0
#1952-53	0.0	0.0	0.0	0.0	T	T	T	T	0.5	T	0.0	0.0	0.5
1953-54	0.0	0.0	0.0	0.0	T	T	1.6	0.0	0.0	T	0.0	0.0	1.6
1954-55	0.0	0.0	0.0	0.0	0.0	3.6	13.8	T	T	0.0	0.0	0.0	17.4
1955-56	0.0	0.0	0.0	0.0	0.0	0.9	0.4	0.0	T	T	0.0	0.0	1.3
1956-57	0.0	0.0	0.0	0.0	T	T	4.1	T	T	T	0.0	0.0	4.1
1957-58	0.0	0.0	0.0	0.0	0.0	1.1	3.0	0.4	T	0.0	0.0	0.0	4.5
1958-59	0.0	0.0	0.0	0.0	0.0	14.7	1.1	0.0	T	0.0	0.0	0.0	15.8
1959-60	0.0	0.0	0.0	0.0	T	T	T	3.9	7.9	0.0	0.0	0.0	11.8
1960-61	0.0	0.0	0.0	0.0	0.0	0.7	3.1	1.2	0.2	0.0	0.0	0.0	5.0
1961-62	0.0	0.0	0.0	0.0	T	T	11.9	0.0	1.2	T	0.0	0.0	13.9
1962-63	0.0	0.0	0.3	0.0	0.0	4.3	1.9	7.5	T	0.0	0.0	0.0	13.9
1963-64	0.0	0.0	0.0	0.0	0.0	T	T	4.8	1.0	1.2	0.0	0.0	8.0
1964-65	0.0	0.0	0.0	0.0	T	0.0	10.6	3.9	T	0.0	0.0	0.0	14.5
1965-66	0.0	0.0	0.0	0.0	0.0	T	14.2	0.5	0.0	0.0	0.0	0.0	14.7
1966-67	0.0	0.0	0.0	0.0	T	1.0	4.2	5.1	T	0.0	0.0	0.0	10.3
1967-68	0.0	0.0	0.0	0.0	T	3.6	1.5	2.0	0.9	0.0	0.0	0.0	7.3
1968-69	0.0	0.0	0.0	0.0	T	3.8	T	0.8	1.9	0.0	0.0	0.0	6.5
1969-70	0.0	0.0	0.0	0.0	0.0	T	3.0	2.8	T	0.0	0.0	0.0	5.8
1970-71	0.0	0.0	0.0	0.0	T	T	T	2.4	4.2	T	0.0	0.0	6.6
1971-72	0.0	0.0	0.0	0.0	T	T	0.0	1.8	T	T	0.0	0.0	1.8
1972-73	0.0	0.0	0.0	0.0	T	0.0	9.1	4.7	T	0.6	0.0	0.0	13.8
1973-74	0.0	0.0	0.0	0.0	0.0	1.4	T	0.9	7.2	0.0	0.0	0.0	9.8
1974-75	0.0	0.0	0.0	0.0	0.0	T							
RECORD MEAN	0.0	0.0	0.0	0.0	T	1.3	3.2	1.9	1.6	T	0.0	0.0	7.6

# Indicates a station move or relocation of instruments. See Station Location table.

Record mean values above are means through the current year for the period beginning in 1875 for temperature, 1871 for precipitation, and 1949 for snowfall. Data are from City Office locations through 1952.

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CHAPTER 12

VENTILATION AND INFILTRATION

The largest contributor to heat loss in buildings (particularly in well insulated buildings) is infiltration and exfiltration.

WINTER

When exhaust fans are turned on, fireplaces operated or clothes dryers vented, the air pressure within the house is lowered and cold outside air seeps in through cracks around windows, doors and construction joints.

When winds blow against the house, pressure differentials can cause infiltration on one side and exfiltration on the opposite side.

The NASA team and A/E design team have recommended that the house be sealed as tightly as possible and that necessary ventilation air be preheated by exhaust air through use of an air-to-air heat exchanger if a cost effective version small enough for a single family house can be developed.

SPRING AND FALL

The mechanical air conditioning season can be shortened substantially if proper ventilation of the house is provided.

All windows and glass areas of the Project TECH house are operable, to permit the best possible natural ventilation. In warm weather, when there is no breeze, an attic exhaust fan draws air through ceiling registers and exhausts it outside through the chimney "belvedere". Reduced pressure in the house pulls in cooler outside air through windows and sliding doors.

SUMMER

On cool summer evenings the use of the natural ventilating characteristics of the TECH house can reduce the energy cost of air conditioning while the heat pump is cooling the water storage for the next hot period.

RECOMMENDATIONS

1. The 6 mil polyethylene vapor barrier on the inside of the exterior wall studs and ceiling rafters should be overlapped and all joints and staple holes should be taped with polyethylene tape to provide a continuous vapor and infiltration barrier.

2. Windows should be carefully sealed at rough openings with foam or sealant to prevent air infiltration.

3. If possible all fresh air and exhaust air should enter and leave the building through controlled openings rather than cracks.

4. Windows and doors with low rates of infiltration are recommended.

5. Steel covered, urethane filled entry and exit doors with refrigerator type magnetic seals are recommended.

6. Glass doors and separate combustion air supply for fireplaces are recommended.

7. Crawl space ventilators should be closed in winter.

8. Vestibules or air locks at entry doors are recommended.

9. Protection of the north side of the house from winter wind by planting of evergreen trees is recommended.

CHAPTER 13

FIREPLACES

The use of fireplaces is primarily aesthetic, in this age of central heating systems, since they tend to lose as much heat through the flue as they contribute by radiation and conduction to their surroundings.

The NASA team and the A/E design team studied ways to make fireplaces more efficient and ways to add some of their heat to the storage system.

RECOMMENDATIONS

1. Provide fireplaces with fresh combustion air from outside by means of a duct directly to the lower part of the firebox.
2. Provide fireplace openings with glass doors to reduce exfiltration loss through chimney flue. (commercially available)
3. Use double wall metal firebox which heats room air by convection. (commercially available)
4. Construct a coil in firebox which heats water and transfers it to the heat storage tank while a fire is burning.

Note: For purposes of heating cost calculations (Chapter 11) net gain from fireplaces was not included although it is estimated that burning one cord of good split hardwood could reduce the annual heating requirement of HG1C by 5×10^6 Btu or 1470 Kwh

CHAPTER 14

COST ESTIMATES

The A/E design team has estiamted the initial cost of Project TECH house HG1D at $52,142 if built by a home-building contractor in Norfolk assuming "mass production" prices for all components.

The expected construction cost to NASA could vary substantially depending on costs of custom made components, landscaping, special facilities for visitors, special consideration for instrumentation and display, spcialized controls and changes made during construction. The A/E design team has estimated that under ideal conditions a minimum of $78,133 would be required for the construction of the residence plus a minimum of site work. In order to cover the items listed above, and to provide for furnishings and decorating, the A/E design team recommends a budget of at least $100,000 assuming no contributions are accepted from manufacturers.

Numerous offers of donations of materials and components were received but it should be made clear that in no case was a material, component, assembly, appliance or other item selected or recommended by the A/E design team unless in their judgement it was determined to best fulfill the goals of the project.

A detailed cost estimate breakdown is included in Appendix IV.

PROJECT TECH

APPENDIX I

COMPONENT AND ASSEMBLY COST EFFECTIVENESS STUDY

CONTENTS

1. INTRODUCTION

The goal of this study is to determine the optimum assembly construction and respective insulating values for walls, roofs, ceilings, floors, and thermal shutters for Project TECH. Doors and windows are also studied for their insulating and infiltration performances versus cost.

In order to realistically compare costs, this study makes these assumptions:

> that energy costs are expected to increase by 10% per year,
>
> that the mortgage term is 20 years,
>
> that the mortgage interest rate is 10%.

A component or assembly was deemed to be "cost-effective" if it satisfied the following test:

> "The added initial cost (through 20 year mortgage payments) of the assembly or component (or its estimated added initial cost by 1981) must be repaid to the buyer through energy or other savings effected by the assembly or component over the life of the mortgage."

Where the average yearly energy cost savings is greater than the yearly mortgage amount, the assembly is cost effective. The larger this difference the greater the cost effectiveness and energy dollar savings.

The most cost effective assembly is not always the greatest energy saver. This study assumes that the consumer would choose which assembly to use based solely on economic considerations.

2. ASSEMBLY THERMAL RESISTANCE AND CONSTRUCTION COST PER SQUARE FOOT CALCULATIONS

The total thermal resistance (R) for a construction is calculated by listing the components of the construction and by consulting a reference, in this case Architectural Graphic Standards or a manufacturer's specifications, for the thermal assistance (R-value) of the individual components. The values for the individual components are then added for the total thermal resistance (R) of the section. Correcting this value for an average square foot as it would be constructed is a further refinement used in this study.

The total construction cost of an assembly is calculated by listing the components of the construction and by consulting a reference, in this case a listing from the 1975 Dodge Manual for Building Construction, Pricing and Scheduling, for installation, labor, and material costs. It is the average square foot of the assembly that is being costed so all values used are in these units. These labor and material costs are then totaled and where necessary, adjusted to the Norfolk area.

Item	Description	R	Cost/SF
WALL ASSEMBLY #1	2 x 4 stud wall w/3 1/2" fiberglass	14.48	1.60

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" sheathing,plywood	0.36
3 1/2" fiberglass	13.00
1/2" gypsum board	0.45
inside air surface	0.68
	15.47 = R
	14.48 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
2 x 4 plate (3)	$0.12/SF	$0.06/SF	
2 x 4 stud	0.15	0.13	
sheathing	0.17	0.19	
siding	0.26	0.50	
1/2" gypsum board	0.12	0.12	
3 1/2" fiberglass	0.09	0.11	
	0.91	1.11	
Adjusted for Norfolk	.62	.98	$1.60/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #2	2 x 4 stud wall w/ styrofoam sheathing	22.58	1.97

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
styrofoam 1 1/2"	8.12
3 1/2" fiberglass	13.00
1/2" gypsum board	0.45
inside air surface	0.68
	23.57 = R
	22.58 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
2 x 4 plate (3)	$0.12/SF	$0.06/SF	
2 x 4 stud	0.15	0.13	
1 1/2" styrofoam	0.14	0.32	
1/2" plywood sheathing	0.17	0.19	
Wood siding	0.26	0.50	
1/2" gypsum board	0.12	0.12	
3 1/2" fiberglass	0.09	0.11	
	1.05	1.43	
Adjusted for Norfolk	.71	1.26	$1.97/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #3	2 x 4 stud wall w/ tri-polymer foam	17.16	1.70

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
3 1/2" T.P.foam	15.68
1/2" gypsum board	0.45
inside air surface	0.68
	18.15 = R
	17.16 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
2 x 4 plate (3)	$0.12/SF	$0.06/SF	
2 x 4 stud	0.15	0.13	
1/2" sheathing	0.17	0.19	
wood siding	0.26	0.50	
1/2" gypsum board	0.12	0.12	
3 1/2" T.P. foam	0.21	0.14	
	1.03	1.14	
Adjusted for Norfolk	.70	1.00	$1.70/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #4	2 x 4 stud wall w/ tri-polymer foam & styrofoam sheathing	25.28	2.05

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
1 1/2" styrofoam sheathing	8.12
3 1/2" T.P.foam	15.68
1/2" gypsum board	0.45
inside air surface	0.68
	27.27 = R
	25.28 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
2 x 4 plate (3)	$0.12/SF	$0.06/SF	
2 x 4 stud	0.15	0.13	
1/2" plywood sheathing	0.17	0.19	
1 1/2" sheathing	0.14	0.32	
wood siding	0.26	0.50	
1 1/2" gypsum board	0.12	0.12	
3 1/2" T.P.foam	0.21	0.14	
	1.17	1.46	
Adjusted for Norfolk	.77	1.28	$2.05/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #5	2 x 6 stud wall w/ 6" fiberglass	20.38	1.90

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
6" fiberglass	19.00
1/2" gypsum board	0.45
inside air surface	0.68
	21.47 = R
	20.38 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
plate(2 x 6) 3	$0.14/SF	$0.09/SF	
studs (2 x 6)	0.16	0.19	
1/2" plywood	0.17	0.19	
1/2" gypsum board	0.12	0.12	
6" fiberglass	0.18	0.27	
wood siding	0.26	0.50	
	1.03	1.36	
Adjusted for Norfolk	.70	1.20	$1.90/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #6	2 x 6 stud wall w/ 6" fiberglass and 1 1/2" styrofoam sheathing	28.50	2.28

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
styrofoam 1 1/2"	8.12
6" fiberglass	19.00
1/2" gypsum board	0.45
inside air surface	0.68
	29.59 = R
	28.50 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Materials	Total
plate (2 x 6) 3	$0.14/SF	$ 0.09/SF	
studs (2 x 6)	0.16	0.19	
sheathing 1 1/2"	0.14	0.32	
1/2" sheathing	0.17	0.19	
siding	0.26	0.50	
gypsum board	0.12	0.12	
6" fiberglass	0.17	0.19	
	1.17	1.68	
Adjusted for Norfolk	.80	1.48	$2.28/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #7	2 x 6 stud wall w/ tri-polymer foam	24.68	1.91

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" sheathing	0.36
5" tri-polymer	23.30
1/2" gypsum board	0.45
inside air surface	0.68
	25.77 = R
	24.68 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
wood siding	$0.26/SF	$0.50/SF	
1/2" sheathing	0.17	0.19	
2 x 6 plate	0.14	0.09	
2 x 6 stud	0.16	0.19	
1/2" gypsum board	0.12	0.12	
5" tri-polymer	0.30	0.20	
	1.15	1.29	
Adjusted for Norfolk	.78	1.13	$1.91/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #8	2 x 6 stud wall w/ 5 1/2" tri-polymer & 1 1/2" styrofoam	32.80	2.33

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
1 1/2" styrofoam sheathing	8.12
5 1/2" tri-polymer	24.64
1/2" gypsum board	0.45
inside air surface	0.68
	33.89 = R
	32.80 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
wood siding	$0.26/SF	$0.50/SF	
1/2" plywood sheathing	0.17	0.19	
1 1/2" styrofoam	0.14	0.32	
2 x 6 plate	0.14	0.09	
2 x 6 stud	0.16	0.19	
1/2" gypsum board	0.12	0.12	
5 1/2" tri-polymer	0.33	0.22	
	1.32	1.63	
Adjusted for Norfolk	.90	1.43	$2.33/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #9	2 x 4 staggered stud wall on 2 x 6 plate w/urethane foam	43.62	3.96

THERMAL RESISTANCE CALCULATION

Item	R
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
foam insulation 5"	45.00
1/2" gypsum board	0.45
inside air surface	0.68
	47.47 = R
	43.62 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
2 x 6 plate (3)	$0.14/SF	$0.09/SF	
2 x 4 stud (2)	0.29	0.25	
1/2" sheathing	0.17	0.19	
siding	0.26	0.50	
1/2" gypsum board	0.12	0.12	
urethane (4.5")	0.77	2.00	
	1.75	3 15	
Adjusted for Norfolk	1.19	2.77	$3.96/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #10	2 x 4 staggered stud wall on 2 x 6 plate w/tri-polymer foam	24.68	2.09

THERMAL RESISTANCE CALCULATION

Item	Tri-polymer R
outside air surface	0.17
wood siding	0.81
1/2" plywood sheathing	0.36
foamed insulation	24.64
1/2" gypsum board	0.45
inside air surface	0.68
	27.11 = R
	24.68 = R (adjusted for studs)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
2 x 6 plate (3)	$0.14/SF	$0.09/SF	
2 x 4 stud (2)	0.29	0.25	
1/2" sheathing	0.17	0.19	
siding	0.26	0.50	
1/2" gypsum board	0.12	0.12	
t.p.foam (5.4")	0.32	0.22	
	1.30	1.37	
Adjusted for Norfolk	.88	1.21	$2.09/SF

Ite-	Description	R	Cost/SF
WALL ASS .BLY #11	Masonry cavity wall w/3" urethane	29.71	6.52

THERMAL RESISTANCE CALCULATION

Item	R Value
ouside air surface	0.17
exterior face brick	0.30
3" urethane	27.00
8" CMU	1.11
1/2" gypsum board	0.45
inside air surface	0.68
	29.71 = R

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
ext. face brick	$2.92/SF	$1.51/SF	
3" urethane	0.57	1.40	
8" CMU	1.36	0.54	
1/2" gypsum board	0.12	0.12	
	$4.97	$3.57	
Adjusted fcr Norfolk	$3.38	$3.14	$6.52/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #12	Masonry cavity wall w/4" urethane	38.71	6.94

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
exterior face brick	0.30
4" urethane	36.00
8" CMU	1.11
1/2" gypsum board	0.45
inside air surface	0.68
	38.71 = R

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
ext. face brick	$2.92/SF	$1.51/SF	
4" urethane	0.67	1.80	
8" CMU	1.36	0.54	
1/2" gypsum board	0.12	0.12	
	5.07	3.97	
Adjusted for Norfolk	3.45	3.49	$6.94/SF

Item	Description	R	Cost/SF
WALL ASSEMBLY #13	Masonry cavity wall w/5" tri-polymer	25.11	5.29

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
exterior face brick	0.30
5" tri-polymer	22.40
8" CMU	1.11
1/2" gypsum board	0.45
inside air surface	0.68
	25.11 = R

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
ext. face brick	$2.92/SF	$1.51/SF	
5" tri-polymer	0.30	0.20	
8" CMU	1.36	0.54	
1/2" gypsum board	0.12	0.12	
	4.70	2.37	
Adjusted for Norfolk	3.20	2.09	$5.29/SF

Notes: This construction assembly would have integral heat storage characteristics. Extra foundation costs would be necessary. CMU exterior face would lower cost significantly; costs not available.

Item	Description	R	Cost/SF
WALL ASSEMBLY #14	14" unit block (8" CMU/4" urethane/ 2" facing)	33.44	4.10

THERMAL RESISTANCE CALCULATION

Item	R Value
outside air surface	0.17
ext. facing	0.30
4" urethane @9	36.00
CMU 8"	1.11
1/2" gypsum board	0.45
inside air surface	0.68
	38.71 = R
	33.44 = R (adjusted for mortar joint)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
Unit block	$2.02/SF	$2.53/SF	
1/2" gypsum board	0.12	0.12	
	2.14	2.65	
Adjusted for Norfolk	1.46	2.64	$4.10/SF

Note: These cost figures do not include transportation costs.

Item	Description	R	Cost/SF
Roof/ceiling Assembly #1	Flat ceiling 6" fiberglass	22.09	0.22

THERMAL RESISTANCE CALCULATION

Item	R Value
Attic air surface	0.17
1/2" attic flooring	0.36
6" fiberglass	22.00
1/2" gypsum board	0.45
inside air surface	0.61
	23.59 = R
	22.09 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material	Cost
6" fiberglass	$0.09/SF	$0.18/SF	
Adjusted for Norfolk	0.06	0.16	$0.22/SF

Item	Description	R	Cost/SF
Roof/ceiling Assembly #2	Flat ceiling 6" tri-polymer foam	26.37	0.57

THERMAL RESISTANCE CALCULATION

Item	R Value
attic air surface	0.17
1/2" attic flooring	0.36
6" tri-polymer foam	26.88
1/2" gypsum board	0.45
inside air surface	0.61
	28.47 = R
	26.37 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material	Cost
6" foam	$0.36/SF	$0.24/SF	
Adjusted for Norfolk	0.25	0.21	$0.46/SF

Item	Description	R	Cost/SF
Roof/ceiling Assembly #3	Flat ceiling 7 1/2" tri-polymer foam	32.29	0.58

THERMAL RESISTANCE CALCULATION

Item	R Value
attic air surface	0.17
1/2" attic flooring	0.36
7 1/2" tri-polymer foam	33.60
1/2" gypsum board	0.45
inside air surface	0.61
	35.19 = R
	32.29 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material	Cost
7 1/2" foam	$0.45/SF	$0.30/SF	
Adjusted for Norfolk	0.31	0.27	$0.58/SF

Item	Description	R	Cost/SF
Roof/ceiling Assembly #4	Flat ceiling w/ 1 1/2" styrofoam	30.23	0.60

THERMAL RESISTANCE CALCULATION

Item	R Value
attic air surface	0.17
1/2" attic flooring	0.36
1 1/2" styrofoam	8.14
6" fiberglass	22.00
1/2" gypsum board	0.45
inside air surface	0.61
	31.73 = R
	30.23 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material	Cost
1 1/2" styrofoam	$0.14/SF	$0.32/SF	
6" fiberglass	0.09	0.18	
	0.23	0.50	
Adjusted for Norfolk	0.16	0.44	$0.60/SF

Item	Description	R	Cost/SF
Roof/ceiling Assembly #5	6" fiberglass @ ceiling w/6" fiberglass @roof flat ceiling	44.39	$0.50

THERMAL RESISTANCE CALCULATION

Item	R Value
exterior air surface	0.17
asphalt shingles	0.44
1/2" sheathing	0.36
6" fiberglass	22.00
attic air space	1.00
1/2" attic floor	0.36
6" fiberglass	22.00
1/2" gypsum board	0.45
inside air surface	0.61
	47.39 = R
	44.39 = R (adjusted for joists)

INSTALLATION COST CALCULATION

Item	Labor	Material	Cost
6" fiberglass @ceiling	$0.09/SF	$0.18/SF	
6" fiberglass @roof	0.11	0.23	
	0.20	0.41	
Adjusted for Norfolk	0.14	0.36	$0.50/SF

Item	Description	R	Cost/SF
Roof/Ceiling Assembly #6	6" fiberglass, ceiling @underside of roof	22.63	$0.22

THERMAL RESISTANCE CALCULATION

Item	R Value
exterior air surface	0.17
shingles & felt	0.44
1/2" sheathing	0.36
6" fiberglass	22.00
1/2" gypsum board	0.45
inside air surface	0.61
	24.03 = R
	22.63 = R (adjusted for joists)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
6" fiberglass	$0.09/SF	$0.18/SF	
Adjusted for Norfolk	0.06	0.16	$0.22/SF

Item	Description	R	Cost/SF
Roof/Ceiling Assembly #7	6" fiberglass w/1" styrofoam ceiling @underside of roof	28.04	0.49

THERMAL RESISTANCE CALCULATION

Item	R Value
exterior air surface	0.17
shingles	0.44
1/2" sheathing	0.36
1" styrofoam	5.41
6" fiberglass	22.00
1/2" gypsum board	0.45
inside air surface	0.61
	29.44 = R
	28.04 = R (adjusted for joists)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
1" styrofoam	$0.15/SF	$0.19/SF	
6" fiberglass	0.09	0.18	
	0.24	0.37	
Adjusted for Norfolk	0.16	0.33	$0.49/SF

Item	Description	R	Cost/SF
Roof/Ceiling Assembly #8	6" fiberglass w/ 1 1/2" styrofoam ceiling @underside of roof	30.77	0.60

THERMAL RESISTANCE CALCULATION

Item	R Value
exterior air surface	0.17
shingles	0.44
1/2" sheathing	0.36
1 1/2" styrofoam	8.14
6" fiberglass	22.00
1/2" gypsum board	0.45
inside air surface	0.61
	32.17 = R
	30.77 = R (adjusted for joists)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
1 1/2" styrofoam	$0.14/SF	$0.32/SF	
6" fiberglass	0.09	0.18	
	0.23	0.50	
Adjusted for Norfolk	0.16	0.44	$0.60/SF

Item	Description	R	Cost/SF
Roof/ceiling Assembly #9	9 1/4" tri-polymer foam, ceiling @ underside of roof	39.87	0.71

THERMAL RESISTANCE CALCULATION

Item	R Value
exterior air surface	0.17
shingles	0.44
1/2" sheathing	0.36
9 1/4" tri-polymer foam	41.44
1/2" gypsum board	0.45
inside air surface	0.61
	43.47 = R
	39.89 = R (adjusted for joists)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
9 1/4" foam	$0.56/SF	$0.37/SF	
Adjusted for Norfolk	0.38	0.33	$0.71/SF

Item	Description	R	Cost/SF
Roof/Ceiling Assembly #10	6" fiberglass w/ 3 1/2" fiberglass	32.48	$0.43/SF

THERMAL RESISTANCE CALCULATION

Item	R Value
Basic assembly	3.50
6" fiberglass	22.00
3 1/2" fiberglass	13.00
	38.50
	32.48 = R (adjusted for joists)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
6" fiberglass	$.09/SF	$0.18/SF	
3 1/2" fiberglass	.09	0.11	
(2 x 12) versus (2 x 10)	.05	0.01	
	.23	0.30	
Adjustment for Norfolk	.16	0.27	$0.43/SF

Item	Description	R	Cost/sf
#1 Floor	Wood frame floor w/ 6" fiberglass	24.25	$0.22/SF

THERMAL RESISTANCE CALCULATION

Item	R Value
Air surface	0.92
hardwood floor	0.68
subfloor	0.98
Air surface	0.92
6" fiberglass	22.00
	25.50
	24.25 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Materials	Total
6" fiberglass	$0.09/sf	$0.18/sf	
Adjusted for Norfolk	.06	0.16	$0.22/SF

Item	Description	R	Cost/sf
#2 Floor	Wood frame floor w/ 6" fiberglass & 1 1/2" styrofoam	32.37	$0.60/SF

THERMAL RESISTANCE CALCULATION

Item	R Value
Air surface	0.92
hardwood floor	0.68
subfloor	0.98
Air surface	0.92
6" fiberglass	22.00
1 1/2" styrofoam	8.12
	33.62
	32.37 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
6" fiberglass	$0.09/sf	$0.18/sf	
1 1/2" styrofoam	.14	.32	
	.23	.50	
Adjusted for Norfolk	.16	.44	$0.60/SF

Item	Description	R	Cost/sf
#3 Floor	Wood frame floor w/ 9 1/4" urea tri-polymer foam	41.37	$0.93

THERMAL RESISTANCE CALCULATION

Item	R Value
Air surface	0.92
Hardwood floor	0.68
Subfloor	0.98
Air surface	0.92
9 1/4" urea tri-polymer foam	41.44
	44.94
	41.37 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material.	Labor
9 1/4" foam	$0.56/sf	$0.37/sf	
3/8" particle board	.17	.12	
	.73	.49	
Adjusted for Norfolk	.50	.43	$0.93/SF

Item	Description	R	Cost/sf
#4 Floor	wood frame floor w/9 1/4" urea tri-polymer foam & 1 1/2" styrofoam	49.51	$1.09

THERMAL RESISTANCE CALCULATION

Item	R Value
Air surface	0.92
hardwood floor	0.68
subfloor	0.98
Air surface	0.92
9 1/4" urea tri-polymer foam	41.44
1 1/2" styrofoam	8.12
	53.06
	49.51 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Material	Total
9 1/4" urea foam	$0.56/sf	$0.37/sf	
1 1/2" styrofoam	.14	.32	
	.70	.69	
Adjusted for Norfolk	.48	.61	$1.09/SF

Item	Description	R	Cost/sf
#5 Floor	Wood frame floor w/ 6" fiberglass and 3 1/2" fiberglass	35.69	$0.38

THERMAL RESISTANCE CALCULATION

Item	R Value
Air surface	0.92
hardwood floor	0.68
subfloor	0.98
Air surface	0.92
6" fiberglass	22.00
3 1/2" fiberglass	13.00
	38.50
	35.69 = R (adjusted)

INSTALLATION COST CALCULATION

Item	Labor	Materials	Total
6" fiberglass	$0.09/sf	$0.18/sf	
3 1/2" fiberglass	.09	.11	
	.18	.29	
Adjusted for Norfolk	.12	.26	$0.38/SF

3 AVERAGE ENERGY COST CALCULATION

The cost per Kwh in Norfolk this heating season is expected to be $0.05. Assuming this cost increases at 10% per year, the yearly costs are:

Year		$/Kwh
1	1975	$.0500
2	1976	.0550
3	1977	.0605
4	1978	.0665
5	1979	.0732
6	1980	.0805
7	1981	.0886
8	1982	.0974
9	1983	.1072
10	1984	.1179
11	1985	.1297
12	1986	.1427
13	1987	.1569
14	1988	.1726
15	1989	.1899
16	1990	.2089
17	1991	.2297
18	1992	.2527
19	1993	.2780
20	1994	.3058

The average cost over the 20 heating seasons is $.143/Kwh

4 DESCRIPTION OF COMPARISON CALCULATION PROCEDURES, FORMULAS AND DEFINITIONS

4A. Energy consumption and energy cost calculation

The energy required to heat a house for a year is equal to the sum of the amounts of heat lost thru its various assemblies, plus infiltration losses.

The heat lost thru any one of the assemblies is given by the formula:

$$Qy = \frac{24 \times SF \times DDy}{R}$$

Where:

Qy = yearly heat loss thru the assembly being considered in Btu/year

24 = number of hours per day

SF = the surface area of the assembly being considered,in square feet

DDy = heating degree days per year, @Norfolk = 3536 (avg. over past 20 years)

R = thermal resistance of the assembly being considered

The standard description of degree days is: the number of degree-days (65 degree F base) per day is the difference between 65 degrees and the daily mean temperature when the latter is less than 65 degrees.

In this formula, Qy is given in BTU. Cost comparisons will be made using Kwh of electricity as a basis, since continuing availability of fuel oil for space heating is uncertain. The "base" house is assumed to be heated with an air to air heat pump (C.O.P. = 2.0)

$$3400 \text{ BTU} = 1 \text{ Kwh}$$

$$E = \frac{Qy \times \$0.143/\text{Kwh}}{\text{C.O.P.}}$$

Where:

E = average yearly energy cost

$0.143 = average cost per Kwh over 20 years

Qy = yearly space heating requirements

C.O.P. = 2.0

$$\text{delta } E = E \text{ base} - Ex$$

Where:

delta E = change in average yearly cost from base item

E base = average yearly energy cost of base item

Ex = average yearly energy cost of item being considered

Delta E represents the yearly energy dollar amount saved by having the respective assembly instead of the base assembly.

4B. Mortgage Cost Calculation

$$C = SF \times C/SF$$

Where:

C = total construction cost of the assembly being considered

SF = total surface area of the assembly in square feet

C/SF = construction cost per square foot

$$\text{delta C} = \text{C (base)} - \text{C(x)}$$

Where:

delta C = change in construction cost from a base assembly

C(base) = total construction cost of the base assembly

Cx = total construction cost of the assembly being considered

$$\text{My} = \text{delta C} \times .0097 \times 12$$

Where:

My = yearly mortgage payment to amortize the amount of delta C

delta C = change in construction cost from base assembly to assembly under consideration

.0097 = cost per month to amortize $1.00 @a 10% interest rate for a term of 20 years

12 = months per year

My represents the additional yearly dollar amount spent by the home owner to buy the better assembly.

4C. Cost Comparison and Savings Calculation

$$\text{Sy} = \text{delta E} - \text{My}$$

(for positive values of Sy)

Where:

Sy = average yearly savings in dollars

delta E = average yearly energy cost in dollars

Where Sy is negative, there is no savings The assembly is <u>not</u> cost effective.

Comparisons of Sy for each assembly or component show their relative cost effectiveness.

5 SUMMARY COMPARISON CALCULATIONS

WALL ASSEMBLY COST EFFECTIVENESS SUMMARY

Item	Description	Total Additional Mortgage Payments over 20 years	Total Energy Cost savings over base over 20 yrs.	Net $ savings over 20 yrs.
#1(base)	2 x 4 stud w/3½" fiberglass	Base	Base	Base
#2	2 x 4 stud w/3½" fiberglass and 1½" styrofoam	1,073.20	1,101.80	28.60
#3	2 x 4 stud w/3½" urea tri-polymer foam	290.00	479.60	189.60
#4	2 x 4 stud w3½" urea tri-polymer foam and 1½" styrofoam	1,305.40	1,312.20	6.80
#5	2 x 6 stud w/6" fiberglass	870.20	889 20	19.00
#6	2 x 6 stud w/6" fiberglass and 1½" styrofoam	1,972.40	1,511.00	--
#7	2 x 6 stud w/5½" urea tri-polymer foam	899.20	1,269.40	370.20
#8	2 x 6 stud w/5½" urea tri-polymer foam and 1½" styrofoam	2,117.60	1,715.40	--
#9	2 x 4 staggered stud on 2 x 6 plate w/ urethane foam	6,845.60	2,051.80	--
#10	2 x 4 staggered stud on 2 x 6 plate w/ urea tri-polymer foam	1,421.40	1.269.40	--
#11	masonry cavity wall w/3" urethane	14,271.40	1,574.40	--
#12	masonry cavity wall w/4" urethane	15,489.60	1,922.60	--
#13	masonry cavity wall w/5" urea tri-polymer foam	10,703.60	1,300.20	--

WALL ASSEMBLY COST EFFECTIVENESS SUMMARY

item	Description	Total Additional Mortgage Payments over 20 years	Total Energy Cost Savings over base over 20 yrs.	Net $ savings over 20 yrs.
#14	14" unit block w/ 4" urethane core	7,251.80	1,741.60	--

FLAT CEILING - COST EFFECTIVENESS SUMMARY

Item	Description	Total Additional Mortgage Payments over 20 years	Total Energy Cost savings over base over 20 yrs.	Net $ savings over 20 yrs.
#1	(Base) 6" fiberglass	Base	Base	Base
#2	6" urea tri-polymer	895.60	420.40	--
#3	7½" urea tri-polymer	1,343.00	818.00	--
#4	6" fiberglass w/1½" styrofoam	1,418.00	697.20	--
$5	6" fiberglass @ceiling & 6" fiberglass @roof	1,045.00	1,301.00	256.00

SLOPED CEILING - COST EFFECTIVENESS SUMMARY

Item	Description	Total Additional Mortgage Payments over 20 years	Total Energy Cost savings over base over 20 yrs.	Net $ savings over 20 yrs.
#1 (base)	6" fiberglass	Base	Base	Base
#2	6" fiberglass w/ 1" styrofoam	145.80	70.40	--
#3	6" fiberglass w/ 1½" styrofoam	205.20	96.60	--
#4	9¼" tri-polymer	264.60	158.00	--
#5	6" fiberglass w/ 3½" fiberglass	113.40	110.30	--

FLOOR ASSEMBLY - COST EFFECTIVENESS SUMMARY

Item	Description	Total Additional Mortgage Payments over 20 years	Total Energy Cost savings over base over 20 yrs.	Net $ savings over 20 yrs.
#1 (base)	6" fiberglass	Base	Base	Base
#2	6" fiberglass w/ 1½" styrofoam	1,335.80	278.70	--
#3	9¼" urea tri-polymer	2,495.80	459.90	--
#4	9¼" urea tri-polymer w/1½" styrofoam	3,058.20	567.00	--
#5	6" fiberglass w/3½" fiberglass	562.40	356.20	--

Note: Savings are given for a temperature change from house interior to crawl space equal to one half of the change from house to exterior.

C-2

THERMAL SHUTTER COST EFFECTIVENESS SUMMARY

	Total Additional Mortgage Payments Over 20 years	Total Energy Cost Savings over base Over 20 years	Net dollar savings Over 20 years
Window w/ insulating glass	Base	Base	Base
Window w/ insulating glass and thermal shutter (avg. R=7.04 for use pattern)	2,784.20	2,945.40	161.20

WINDOW FRAME - COST EFFECTIVENESS SUMMARY

		Total Additional Mortgage Payments Over 20 Years	Total Energy Cost Savings over Base Over 20 years	Net Dollar Savings Over 20 years
1.	Non-thermal break Alum.	Base	Base	Base
2.	ANDERSON casement	274.20	--	--
3.	PELLA casement	246.60	186.00	--
4.	CARADCO casement	192.40	148.40	--
5.	DURATHERM hopper	237.40	139.20	--
6.	REYNOLDS w/sliding break	28.00	19.40	--
7.	ALCOA w/sliding break	67.40	30.80	--

SLIDING GLASS DOOR - COST EFFECTIVE STUDY

	Total Additional Mortgage Payments Over 20 Years	Total Energy Cost Savings Over Base Over 20 Years	Net Dollar Savings Over 20 Years
Base (Aluminum without thermal break)	Base	Base	Base
ANDERSON (wood)	613.40	156.40	--
REYNOLDS (aluminum with thermal break)	101.20	65.40	--
ACORN (aluminum with thermal break)	147.20	53.40	--

ENTRY DOOR COST EFFECTIVENESS SUMMARY

	Total Additional Mortgage Payments Over 20 Years	Total Energy Cost Savings over base Over 20 Years	Net dollar savings Over 20 Years
Solid wood door w/weatherstripping	Base	Base	Base
Same door with solid storm door	69.80	135.40	65.60
Metal door with polyurethane core and magnetic weather-stripping	23.20	797.60	774.40

6. COMPARISON CALCULATIONS
for walls, ceilings, roofs, floors

Worksheet 1.
Project TECH

WALL ASSEMBLY COST EFFECTIVENESS CALCULATION

	#1 BASE	#2	#3	#4	#5	#6
SF	1246	1246	1246	1246	1246	1246
Hours	24	24	24	24	24	24
DDy	3536	3536	3536	3536	3536	[illegible]
R	14.48	22.53	17.16	25.28	20.38	[illegible]
Q_y (Btu) ($\times 10^6$)	7.303	4.032	6.1[illegible]	4.182	5.183	[illegible]
Q_y (Kwh)	2147.8	1377.3	1812.4	1230.2	1526.0	[illegible]
Q (for COP=2)	1073.9	688.7	[illegible]	615.1	763.0	[illegible]
Avg. Cost/Kwh	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.1[illegible]
E	$ 153.57	$ 98.48	$ 129.59	$ 87.96	$ 109.11	$ 78.04
delta E	BASE	$ 55.09	$ 23.98	$ 65.61	$ 44.46	$ 15.[illegible]
Cost/sf	$ 1.60	$ 1.97	$ 1.70	$ 2.05	$ 1.90	$ 2.20
C	$ 1993.60	$ 2454.62	$ 2118.20	$ 2554.30	$ 2367.40	$ [illegible]
delta C	BASE	461.02	124.60	560.70	373.80	[illegible]
My	BASE	57.66	14.50	65.27	43.51	78.62
Sy	BASE	1.43	9.48	.34	.95	---
Sy x 20	BASE	28.60	189.60	6.80	19.00	---

Worksheet 2
Project TECH

WALL ASSEMBLY COST EFFECTIVENESS CALCULATION

	#7	#8	#9	#10	#11	#12
SF	1246	1246	1246	1246	1246	1246
Hours	24	24	24	24	24	24
DDy	3536	3536	3536	3536	3536	3536
R	24.68	32.80	43.67	24.68	29.71	38.11
Q_y (Btu) ($\times 10^6$)	4.284	3.224	2.424	4.284	3.559	2.731
Q_y (Kwh)	1260.1	948.2	713.0	1260.1	1046.8	803.4
Q (for COP=2)	630.1	474.1	356.5	630.0	523.4	401.7
Avg. Cost/Kwh	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.143
E	$ 90.10	$ 67.80	$ 50.98	$ 90.10	$ 74.85	$ 57.44
delta E	$ 63.47	$ 85.77	$ 102.59	$ 63.47	$ 78.72	$ 96.13
Cost/sf	$ 1.91	$ 2.33	$ 3.96	$ 2.09	$ 6.52	$ 6.94
C	$ 2379.86	$ 2903.18	$ 4934.16	$ 2604.14	$ 8123.92	$ 8647.24
delta C	$ 386.20	$ 909.58	$ 2904.56	$ 610.54	$ 6130.32	$ 6653.64
My	$ 44.96	$ 105.88	$ 342.28	$ 71.07	$ 713.57	$ 774.48
Sy	18.51	—	—	—	—	—
Sy x 20	370.20	—	—	—	—	—

Worksheet 3
Project TECH

WALL ASSEMBLY COST EFFECTIVENESS CALCULATION

	#13	#14				
SF	1240	1240				
Hours	24	24				
DDy	3553	3553				
R	25.11	33.44				
Q_y (Btu) ($x10^6$)	4.211	3.162				
Q_y (Kwh)	1238.6	930.0				
Q (for COP=2)	619.3	465.0				
Avg. Cost/Kwh	$0.143	$0.143				
E	$88.56	$66.50				
delta E	$65.01	$87.03				
Cost/sf	5.29	4.10				
C	6511.34	5108.60				
delta C	4597.74	3115.00				
My	575.18	362.59				
Sy	—	—				
Sy x 20	—	—				

Worksheet 4
Project TECH

FLAT CEILING - COST EFFECTIVENESS CALCULATION

	#1 BASE	#2	#3	#4	#5	
SF	1003	1003	100[illegible]	1003	1003	
Hours	24	24	24	24	24	
DDy	3536	3536	3536	3536	3536	
R	22.09	23.37	32.[illegible]	30.23	44.31	
Q_y (Btu) ($x10^6$)	6.153	5.159	4.213	4.500	3.065	
Q_y (Kwh)	1811.3	1517.3	12[illegible]1	1323.5	901.3	
Q (for COP=2)	905.6	758.6	[illegible]	661.8	450.7	
Avg. Cost/Kwh	$0.143	$0.143	$0.143	$0.143	$0.143	
E	129.50	108.48	85.[illegible]0	94.64	64.45	
delta E	BASE	21.02	40.[illegible]0	34.86	65.05	
Cost/sf	$0.22	$0.46	$0.58	$0.60	$0.50	
C	$352.66	$737.38	$9[illegible]1.[illegible]	$761.80	$801.50	
delta C	BASE	$384.72	$577.03	$609.14	$448.80	
My	BASE	$49.73	$61.17	$70.90	$52.25	
Sy	BASE	—	—	—	$12.30	
Sy x 20	BASE	—	—	—	$256.00	

Worksheet 5
Project TECH

ROOF (SLOPED CEILING) - COST EFFECTIVENESS CALCULATION

	#1 BASE	#2	#3	#4	#5	
SF	232	232	232	232	232	
Hours	24	24	24	24	24	
DDy	3536	3536	3536	3536	3536	
R	22.63	28.04	30.77	39.89	32.48	
Q_y (Btu) ($x10^6$)	.870	.702	.640	.494	.606	
Q_y (Kwh)	255.9	206.5	188.2	145.2	178.3	
Q (for COP=2)	127.9	103.3	94.1	72.6	89.1	
Avg. Cost/Kwh	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.143	
E	$ 18.29	$ 14.77	$ 13.46	$ 10.38	$ 12.75	
delta E	BASE	$ 3.52	$ 4.83	$ 7.90	$ 5.54	
Cost/sf	$ 0.22	$ 0.49	$ 0.60	$ 0.71	$ 0.43	
C	$ 51.04	$ 113.68	$ 139.20	$ 164.72	$ 99.76	
delta C	BASE	$ 62.64	$ 88.16	$ 113.68	$ 48.72	
My	BASE	$ 7.29	$ 10.26	$ 13.23	$ 5.67	
Sy	BASE	—	—	—	—	
Sy x 20	BASE	—	—	—	—	

Worksheet 6
Project TECH

FLOOR ASSEMBLY - COST EFFECTIVENESS CALCULATION

	#1 (BASE)	#2	#3	#4	#5	
SF	1510	1510	1510	1510	1510	
Hours	24	24	24	24	24	
DDy	3536	3536	3536	3536	3536	
R	24.25	32.37	41.37	49.51	35.69	
Q_y (Btu) ($x10^6$)	5.284	3.959	3.098	2.588	3.590	
Q_y (Kwh)	1554.2	1164.3	911.0	761.3	1056.0	
Q (for COP=2)	777.1	582.2	455.5	380.6	528.0	
Avg. Cost/Kwh	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.143	
E	$ 111.13	$ 83.25	$ 65.14	$ 54.43	$ 75.51	
delta E	BASE	$ 27.87	$ 45.99	$ 56.70	$ 35.62	
Cost/sf	$ 0.22	$ 0.60	$ 0.93	$ 1.09	$ 0.38	
C	$ 332.20	$ 906.00	$ 1404.30	$ 1645.90	$ 573.80	
delta C	BASE	$ 573.80	$ 1072.10	$ 1313.70	$ 241.60	
My	BASE	$ 60.79	$ 124.79	$ 152.91	$ 28.12	
Sy		—	—	—	$ 7.50	
Sy x 20						
Sy (1/2 ΔT)	BASE	—	—	—	—	

7. THERMAL SHUTTERS

THERMAL RESISTANCE CALCULATION FOR PROPOSED SHUTTER INSTALLATION

Item	R Value
outside air surface	0.17
insulating glass	1.88
2" air space	1.00
lamite or masonite	0.45
1 1/2" urea tri-polymer	6.72
lamite or masonite	0.45
air surface	0.68
	11.35

THERMAL RESISTANCE CALCULATION FOR WINDOW

Item	R Value
outside air surface	0.17
insulating glass	1.88
air surface	0.68
	2.73

If the thermal shutters are open 12 hours during the day and closed 12 hours at night during the heating season, the average thermal resistance for this use is R = 7.04. This average should be conservatively low because nighttime is colder than daytime and because the shutters could be used more than 12 hours during the coldest winter days.

The cost effectiveness calculation shows that thermal shutters would be cost effective, saving $8.06 a year.

Worksheet 7
Project TECH

THERMAL SHUTTER COST EFFECTIVENESS CALCULATION

	INSULATING GLASS	INSUL. GL. W/THER. SHUTTER				
SF	368	368				
Hours	24	24				
DDy	3336	3336				
R	2.73	7.04				
Q_y (Btu) ($x10^6$)	11.44	4.436				
Q_y (Kwh)	3364.6	1304.7				
Q (for COP=2)	1682.3	652.4				
Avg. Cost/Kwh	$ 0.143	$ 0.143				
E	$ 240.57	$ 93.29				
delta E	BASE	$ 147.27				
Cost/sf	BASE	$ 3.25				
C	BASE	$ 1196.00				
delta C	BASE	$ 1196.00				
My	BASE	$ 139.21				
Sy	BASE	$ 8.06				
Sy x 20	BASE	$ 161.20				

8. WINDOWS

In this section, general studies are made to determine thermal performance and cost effectiveness of:

1. Double versus triple glazing,

2. Double versus triple glazing with thermal shutters in use,

3. Wood versus aluminum (with thermal break design) frames.

Other important aspects of window selection such as durability, ease of operation and maintenance and aesthetic preference were not considered in this part of the study.

The results of the studies are:

1. Triple glazing is cost effective compared to double glazing.

2. Triple glazing is not cost effective compared to double glazing when thermal shutters are used as described in Section 7.

3. Aluminum with thermal break and wood windows are not cost effective compared to non-thermal break aluminum windows.

Using aluminum thermal break or wood windows may be justified where condensation is a concern or where the afore mentioned aspects of window selection, not considered in this part of the study, are important considerations. If study 3 had been performed in combination with thermal shutters, the net effect of the more thermally efficient frames would have been reduced. Norfolk has a mild climate. Further north, aluminum thermal break and wood windows may well become cost effective.

Worksheet 8
Project TECH

DOUBLE VS. TRIPLE GLAZING - COST EFFECTIVENESS CALCULATION

	DOUBLE GLAZED	TRIPLE GLAZED				
SF	16	16				
Hours	24	24				
DDy	3536	3536				
R (INCL AIR SURF)	2.73	3.62				
Q_y (Btu) ($x10^6$)	.497	3.75				
Q_y (Kwh)	146.3	110.3				
Q (for COP=2)	73.2	55.2				
Avg. Cost/Kwh	$ 0.143	$ 0.143				
E	$ 10.46	$ 7.89				
delta E	BASE	$ 2.57				
Cost/sf						
C						
delta C	BASE	15 00*				
My	BASE	1.74				
Sy	BASE	.83				
Sy x 20	BASE	$ 16.60				

Worksneet 9
Project TECH

DOUBLE VERSUS TRIPLE GLAZING WITH THERMAL SHUTTERS IN USE - COST EFFECTIVENESS CALCUALTION

	DOUBLE GLAZED	TRIPLE GLAZED				
Sf	16	16				
Hours	24	24				
DDy	3536	3536				
R (INCL. AIR [illegible] F.)	7.[illegible]4	7.34				
Q_y (Btu) (x10^6)	.193	.185				
Q_y (Kwh)	56.7	54.4				
Q (for COP=2)	28.4	27.2				
Avg. Cost/Kwh	$ 0.143	$ 0.143				
E	$ 4.06	$ 3.89				
delta E	BASE	$ 0.17				
Cost/sf						
C						
delta C	BASE	$ 15 00				
My	BASE	1.74				
Sy	BASE	—				
Sy x 20	BASE	—				

Worksheet 10
Project TECH

WINDOW FRAME TYPE
COST EFFECTIVENESS STUDY

	1 AL/NO BREAK	ANDERSEN WO/CASEM'T	PELLA ~~WIDTH~~	CARADCO W/CASEM'T	DURATHERM WD/HOPPER
SF	16	16	16	16	16
Hours	24	24	24	24	24
DDy	3536	3536	3536	3536	3536
R (INCL AIR SURFACE)	2.21	2.81	2.74	2.45	2.74
Qc (x10^5)	6.14	4.83	4.96	5.54	4.96
CFM/lfc	.22	.25	.036	.05	.13
Crack length	20	24	24	24	16
Minutes/hr	60	60	60	60	60
Volume/hr	264	360	52	72	125
Constant	1528	1528	1528	1528	1528
Q_I (x10^5)	4.03	5.50	.79	1.10	1.90
Q (Btu)(x10^5)	10.17	10.33	5.75	6.64	6.86
Q (Kwh)	299.2	303.9	169.0	195.4	201.8
Q (for COP=2)	149.6	152.	84.5	97.7	100.9
Avg.Cost/Kwh	$ 0.143	$ 0.143	$ 0.143	$ 0.143	$ 0.143
E	$ 21.39	$ 21.73	$ 12.09	$ 13.97	$ 14.43
delta E	BASE	-.34	$ 9.30	$ 7.42	6.96
Cost/sf					
C	$ 70.00	$ 190.00	$ 176.00	$ 152.00	$ 172.00
delta C	BASE	$ 120.00	$ 106.00	$ 82.62	$ 102.00
My	BASE	$ 13.96	$ 12.33	$ 9.62	$ 11.07
Sy	BASE	—	—	—	—
Sy x 20	BASE	—	—	—	—

Constant = .23 x .075 x 24 x DDy

Q (Btu) = $Q_I + Qc$

WINDOW FRAME TYPE
COST EFFECTIVENESS STUDY

Worksheet 11
Project TECH

	REYNOLDS W/BREAK	ALCOA W/BREAK			
SF	16	16			
Hours	24	24			
DDy	3536	3536			
R (INCL. AIR SURFACES)	2.39	2.60			
Qc ($\times 10^5$)	5.86	5.22			
CFM/lfc	.22	.23			
Crack length	20	20			
Minutes/hr	60	60			
Volume/hr	264	276			
Constant	1520	1520			
Q_I ($\times 10^5$)	4.03	4.22			
Q (Btu)	9.71	9.44			
Q (Kwh) ($\times 10^5$)	285.6	277.6			
Q (for COP=2)	142.8	138.8			
Avg.Cost/Kwh	\$0.143	\$0.143			
E	\$20.42	\$19.85			
delta E	.97	1.54			
Cost/sf					
C	\$82.00	\$99.00			
delta C	\$12.00	\$29.00			
My	\$.140	\$3.37			
Sy	—	—			
Sy x 20	—	—			

Constant = .23 x .075 x 24 x DDy

Q (Btu) = Q_I + Qc

9. SLIDING GLASS DOORS

In this section studies were made to determine the thermal performance and cost effectivseness of these two types of sliding glass doors:

1. Wood frame

2. Aluminum frame with thermal break design

Other important aspects of door selection such as durability, ease of operation, maintenance, and aesthetic preference were not considered in this part of the study.

The results of the study are that aluminum thermal break and wood sliding glass doors are not cost effective compared to non-thermal break aluminum doors.

Using aluminum thermal break or wood sliding glass doors may be justified where condensation is a problem or where the aforementioned aspects of door selection not considered in this part of the study are important considerations. If the study had been performed in combination with thermal shutters, the net effect of the more thermally efficient frames would have been reduced. Further north in a more harsh climate than Norfolk's, aluminum thermal break and/or wood windows may well be cost effective.

SLIDING GLASS DOOR
COST EFFECTIVENESS STUDY

Worksheet 12
Project TECH

	BASE AL. W/O BREAK	ANDERSEN WOOD	REYNOLDS ALUM W/BREAK	ACORN AL W/BREAK	
SF	54	54	54	54	
Hours	24	24	24	24	
DDy	3536	3536	3536	3536	
R (INCL AIR SURF.)	2.21	2.70	2.39	2.39	
Qc ($\times 10^5$)	20.74	16.97	19.17	19.17	
CFM/lfc	.08/sf	.25/lfc	.08	.086	
Crack length	54 sf.	17.5	54	54	
Minutes/hr	60	60	60	60	
Volume/hr	259.2	262.5	259.2	278.6	
Constant	1528	1528	1528	1528	
Q_I ($\times 10^5$)	3.96	4.01	3.96	4.26	
Q (Btu)	24.70	20.98	23.13	23.43	
Q (Kwh)	726.5	617.1	680.4	689.2	
Q (for COP=2)	363.2	308.5	340.2	344.6	
Avg.Cost/Kwh	$ 0.143	$ 0.143	$ 0.143	$ 0.143	
E	$ 51.94	$ 44.12	$ 48.65	$ 49.27	
delta E	BASE	7.82	3.27	2.67	
Cost/sf					
C	$ 246.50	$ 510.00	$ 290.00	$ 310.00	
delta C	BASE	$ 263.50	$ 43.50	$ 63.50	
My	BASE	$ 30.07	$ 5.06	$ 7.39	
Sy	BASE	—	—	—	
Sy x 20	BASE	—	—	—	

Constant = .23 x .075 x 24 x DDy

Q (Btu) = Q_I + Qc

10. ENTRY DOORS

In this section, general studies are made to determine the thermal performance and cost effectiveness of these types of entry doors:

1. Solid wood w/weatherstripping
2. Solid wood w/weatherstripping and solid storm door
3. Metal faced, polyurethane core door w/magnetic weatherstripping

Other important aspects of door selection such as durability, ease of operation, maintenance, and aesthetic preference were not considered in this part of the study.

The results show that the metal faced door by Therma-tru would save $38.72 a year

ENTRY DOOR COST EFFECTIVENESS CALCULATION

	SOLID WOOD WEATHERSTRIPPED	SOLID WOOD W/ WOOD STORM	METAL FACED URETHANE CORE		
SF	20.25	20.25	20.25		
Hours	24	24	24		
DDy	3530	3530	3530		
R	2.73	5.60	13.50		
Qc ($\times 10^5$)	6.29	3.07	1.27		
CFM/lfc	.85	.85	.07		
Crack length	19.5	19.5	17.5		
Minutes/hr	60	60	60		
Volume/hr	994.5	994.5	81.9		
Constant	1520	1520	1520		
Q_I ($\times 10^5$)	15.2	15.2	1.25		
Q (Btu) ($\times 10^5$)	21.49	18.27	2.52		
Q (Kwh)	632.1	537.4	74.1		
Q (for COP=2)	316	268.7	37.1		
Avg.Cost/Kwh	$ 0.143	$ 0.143	$ 0.143		
E	$ 45.19	$ 38.42	$ 5.30		
delta E	BASE	$ 6.77	$ 39.88		
Cost/sf					
C	$ 70.00	$ 100.00	$ 80.00		
delta C	BASE	$ 30.00	$ 10.00		
My	BASE	$ 3.49	$ 1.16		
Sy	BASE	$ 3.28	$ 38.72		
Sy x 20	BASE	$ 65.60	$ 774.40		

Constant = .23 x .075 x 24 x DDy

Q (Btu) = Q_I + Qc

11 OBSERVATIONS AND CONCLUSIONS

1. Fiberglass insulation, if made in 8" deep batts for 2 x 10 ceilings and 10" deep batts for 2 x 12 ceilings with R's of 27 to 34, would be a desirable product for use in roof and ceiling construction.

2. Urea tri-polymer foam (a non-petroleum based product that gives off no toxic smoke or gases when subjected to flame, a flame spread rating of 5, fuel contribution of 0 in ASTM 84-70, accepted by the N.Y.City Building Department as non-combustible thermal insulation) is a new product that will be a very desirable insulator in cavity situations where its shrinkage provides adequate venting or where the construction is otherwise vented.

3. Thermal shutters or insulating curtains, with R=7.5 and up, bought for $3.25 would be desirable products especially if sold as part of a window package.

4. Door and window manufacturers should give the thermal and infiltration performance as a matter of course. The effect of frame material on thermal performance was not studied because such data was generally unavailable from manufacturers.

5. Masonry wall construction has several advantages that did not show up in this study. A great mass within the insulated layer of a building becomes an excellent heat storage. Warm walls are more

comfortable. Peak heating and cooling loads are leveled. Norfolk is mild enough where this alternative may be economically difficult to achieve. Perhaps a less expensive masonry wall or assembly would be justifiable in more northern applications. See bibliography item <u>New Insights Into Energy Use and Conservation in Structures</u>, National Concrete Masonry Assoc.

6. Further refinements of assemblies during the final design phase of the Project TECH house could reduce the design heat loss but infiltration contributes such a large percentage of the design heat loss that extra effort and study should be concentrated in that area.

PROJECT TECH

APPENDIX II

ENERGY REQUIREMENTS for HEATING

CONTENTS

INTRODUCTION

Heat loss/gain calculations are generally based on ASHRAE methods for residences.

The base house is identical in configuration to HG1D except its insulation which is standard for 1974 electrically heated houses and its infiltration loss which is calculated at 1.5 air changes per hour compared to 1.0 air changes per hour for HG1D (due to the greater tightness of HG1D). In addition it has been assumed that approximately 1/3 of the heat from exhausted air can be transferred (through an air to air heat exchanger) to incoming fresh air in the HG1D house.

Of the heat gained by insolation through south windows approximately 25% is usable in the Base house. The remainder would probably be vented to the outside when an overheat condition occurs. The HG1D house can (through its cooling system) transfer some of this excess "solar" heat to storage rather than venting it. It has been estimated that 50% or more of the heat gained by insolation in HG1D can contribute to space heating requirements. These factors have been taken into account and are reflected in the total heat energy requirements of both the base house and HG1D.

1. DESIGN HEAT LOSS FORMULAE

Design Heat Loss = Qc total + Q_I

HEAT LOSS FORMULA - CONVECTION/CONDUCTION/RADIATION

$$Qc = \frac{\text{delta t} \times SF}{R} = U \times \text{delta t} \times SF$$

Where:

Qc = heat loss due to convection/conduction/radiation in BTU/hr for item

Qc total = sum of Qc for house

delta t = maximum expected temperature difference from inside to outside temperature.

delta t = 68 degrees inside - 15 degrees outside = 53 degrees

SF = area in square feet of item being considered for space being considered

R = thermal resistance of the item being considered in BTU/Hr/degrees F

$$R = \frac{1}{U}$$

HEAT LOSS FORMULA - INFILTRATION

Q_I = cu.ft./hr. x .24 x .075 x delta t x r

Where:

Q_I = heat loss due to infiltration in BTU/hr.

cu/ft/hr = volume of air infiltrating per hour
1 air change/hr = volume of house x 1

.24 = specific heat of air, the number of BTU needed to raise one pound of air one degree F.

.075 = average density of air in pounds per cubic foot

delta t = maximum expected temperature difference from inside to outside - temperature given by ASHRAE handbook for specific locations

r = recovery rate: that part of infiltration heat losses <u>not</u> recaptured by the air handling system

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2.

DESIGN HEAT LOSS = U x Δt x SF   PROJECT: BASE HOUSE   DATE: 8/12/75

ITEM	U	Δt	AREA TOTALS ↓	LR SF	LR Btu	KIT. DIN SF	KIT. DIN Btu	VEST. SF	VEST. Btu	HALL SF	HALL Btu	M BATH SF	M BATH Btu	BATH 2 SF	BATH 2 Btu	M B R SF	M B R Btu	BR 2 SF	BR 2 Btu	BR 3 SF	BR 3 Btu	TOTALS Btu/h	%
#1 WALL 3½" FIBERGL. INSUL.	.069	53°	1246	114	417	251	918	100	366	86	315	—		—		535	1956	80	292	80	292	4556	11%
GL. DOORS & WINDOWS ALUM. DOUBLE GL.	.470	53°	368	106	2640	53	1320	—		106	2640	—		—		71	1769	16	399	16	399	9167	23%
SOLID DOOR 1¾" WOOD	.510	53°	40	—		20	541	20	541	—		—		—		—		—		—		1082	3%
#1 FLOOR 6" FIBERGL. INSUL.	.041	20°	1510	296	243	293	240	56	46	135	111	45	37	51	42	324	265	155	127	155	127	1238	3%
#1 FLAT CEILING 6" FIBERGL. INSUL.	.044	53°	1252	58	135	273	636	56	130	135	315	45	105	51	119	324	755	155	361	155	361	2917	7%
#1 SLOPED CEILING 6" FIBERGL. INSUL.	.044	53°	232	228	531	4	9	—		—		—		—		—		—		—		540	1%
#1 HIGH INTERIOR WALLS THRU ATTIC 3½" INSUL.	.078	53°	351	144	595	72	297	—		—		—		—		135	558	—		—		1450	4%
SKYLIGHTS SINGLE DOME	1.15	53°	32	16	975	16	975	—		—		—		—		—		—		—		1950	5%
QcTOTAL																						22900	
@ 1½ AIR CHANGE/HR.		53°																					
INFILTRATION: Formula Used: 1.431 (VOLUME)			12353 cu ft.	2766 cu ft	3958	2288 cu ft	3274	390 cu ft	558	960 cu ft	1374	328 cu ft	469	360 cu ft	515	3005 cu ft	4300	1128 cu ft	1614	1128 cu ft	1614	17676	43%
TOTALS:				9404		8210		1641		4755		611		676		9603		2793		2793		40,576	100%

3. BASE HOUSE HEAT GAIN CALCULATION

Energy Available from Window Insolation During Colder Months

Colder Months	Gross Insolation	Usable Insolation (25%)
Sept.	.96 x 10^6 Btu	24 x 10^6 Btu
Oct.	3.18 x 10^6 Btu	.80 x 10^6 Btu
Nov.	3.34 x 10^6 Btu	.84 x 10^6 Btu
Dec.	3.55 x 10^6 Btu	.89 x 10^6 Btu
Jan.	3.40 x 10^6 Btu	.85 x 10^6 Btu
Feb.	2.67 x 10^6 Btu	.67 x 10^6 Btu
Mar.	.99 x 10^6 Btu	.25 x 10^6 Btu

4. BASE HOUSE HEATING ENERGY REQUIREMENTS

The total heating energy required equals the gross energy required (Qr gross) less insolation heat gain.

$$\text{Qr gross} = \frac{24 \times \text{Qa} \times \text{DDm}}{\text{delta t}}$$

Where:

Qr gross = gross heating energy required in Btu

Qd = design heat loss = 40576 Btu

DDm = degree days per month (average over last 20 years)

24 = hours per day

delta t = inside design temperature - outside design temperature = 53 degrees F

$$\text{Let } f = \frac{24 \times 40576}{53} = 18374 \text{ Btu/degree/day}$$

So that Qr gross = (f)(DDm) btu/month

(4. Base House Heating Energy Requirements cont.)

	f	DDm	Qr gross	Insolation Gain	Total Energy Requirement (Qr net)
Jan	18374	784	14.40 x 10^6 Btu	.85 x 10^6 Btu	13.55 x 10^6 Btu
Feb	18374	677	12.44 x 10^6 Btu	.67 x 10^6 Btu	11.77 x 10^6 Btu
Mar	18374	524	9.63 x 10^6 Btu	.25 x 10^6 Btu	9.38 x 10^6 Btu
April	18374	245	4.50 x 10^6 Btu	--	4.50 x 10^6 Btu
May	18374	74	1.36 x 10^6 Btu	--	1.36 x 10^6 Btu
June	18374	5	.09 x 10^6 Btu	--	.09 x 10^6 Btu
July	18374	0	--	--	0
Aug	18374	0	--	--	0
Sept	18374	12	.22 x 10^6 Btu	.24 x 10^6 Btu	0
Oct	18374	145	2.66 x 10^6 Btu	.80 x 10^6 Btu	1.86 x 10^6 Btu
Nov	18374	399	7.33 x 10^6 Btu	.84 x 10^6 Btu	6.49 x 10^6 Btu
Dec	18374	671	12.33 x 10^6 Btu	.89 x 10^6 Btu	11.44 x 10^6 Btu
Annual Totals		3536	64.96 x 10^6 Btu	4.54 x 10^6 Btu	60.44 x 10^6 Btu

BASE HOUSE ANNUAL HEATING REQUIREMENT = 60.44 x 10^6 Btu

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5.

DESIGN HEAT LOSS = U x Δt x SF PROJECT: NASA HG ID DATE: 8/12/75

ITEM	U	Δt	SF TOTALS	LR SF	LR Btu	K-DIN SF	K-DIN Btu	VESTIBULE SF	VESTIBULE Btu	HALL SF	HALL Btu	M BATH SF	M BATH Btu	BATH 2 SF	BATH 2 Btu	MBR SF	MBR Btu	BR 2 SF	BR 2 Btu	BR 3 SF	BR 3 Btu	TOTALS Btu/h	%
#7 WALL 5½" TRI-POLY FOAM	.041	53°	1246	114	248	251	545	100	217	86	187	—		—		[illegible]	1163	80	174	80	174	2708	15%
GL. DOORS & WINDOWS W/INSUL. SHUTTERS	.142	53°	368	106	793	53	399	—		106	793	—		—		[illegible]	534	16	120	16	120	2769	15%
SOLID DOOR THERMA TRU	.074	53°	40	—		20	78	20	78	—		—		—		—		—		—		156	1%
#2 FLOOR 6" FIBRGL INSUL	.041	20°	1510	296	[illegible]	213	[illegible]	56	46	135	111	45	[illegible]	51	42	324	[illegible]	155	127	155	127	1239	7%
#5 FLAT CEILING 12" FIBRGL INSUL	.0225	53°	1252	58	69	273	[illegible]	56	67	135	161	45	54	51	61	324	[illegible]	155	184	155	184	[illegible]	[illegible]
#1 SLOPED CEILING 6" FIBRGL INSUL	.044	53°	232	228	532	9	7	—		—		—		—		—		—		—		541	[illegible]
HIGH INTERIOR WALLS THRU ATTIC & ROOF 12" INSUL.	.0225	53°	351	144	172	72	86	—		—		—		—		135	161	—		—		419	[illegible]
SKYLIGHTS DOUBLE DOME	.70	53°	32	16	594	16	594	—		—		—		—		—		—		—		1188	6%
Qc TOTAL																						10511	
@ 1 AIR CHANGE/HR. 1/3 HEAT RECOVERY:		53°																					
INFILTRATION: Formula Used: .959 (VOLUME, 2/3			12353 CU.FT.	2766 CU FT	1759	22[illegible] CU FT	1455	390 CU FT	248	960 CU FT	611	328 CU FT	209	360 CU FT	229	3005 CU FT	1911	1128 CU FT	717	1128 CU FT	717	7856	43%
TOTALS:				4415		3731		656		1303		300		332		4421		1322		1322		14367	100%

6. HG1D HEAT GAIN CALCULATION

Energy Available from Window Insolation During Colder Months

	Gross Insolation	Usable Insolation (50%)
Sept	.96 x 10^6 Btu	.48 x 10^6 Btu
Oct	3.18 x 10^6 Btu	1.59 x 10^6 Btu
Nov	3.34 x 10^6 Btu	1.67 x 10^6 Btu
Dec	3.55 x 10^6 Btu	1.78 x 10^6 Btu
Jan	3.40 x 10^6 Btu	1.70 x 10^6 Btu
Feb	2.67 x 10^6 Btu	1.34 x 10^6 Btu
Mar	.99 x 10^6 Btu	.50 x 10^6 Btu

Heating season total 8.58 x 10^6 Btu

7. HG1D HEATING ENERGY REQUIREMENTS

The total heating energy required equals the gross energy required (Qr gross) less insolation heat gain.

$$Qr\ gross = \frac{24 \times Qd \times DDm}{delta\ t}$$

Where:

Qr gross = gross heating energy required in Btu

Qd = design heat loss = 18367 Btu/hr

DDm = degree days per month (average over 20 yr. period)

24 = hours per day

delta t - inside design temperature - outside design temperature = 53 degrees F

$$Let\ f = \frac{24 \times 18367}{53} = 8317\ Btu/degree/day$$

So that Qr gross = (f)(DDm) Btu/month

(7. HG1D Heating Energy Requirements)

	f	DDm	Qr gross	Insolation Gain	Total Heat Energy Requirement (Qr net)
Jan	8317	784	6.52×10^6 Btu	1.70×10^6 Btu	4.82×10^6 Btu
Feb	8317	677	5.63×10^6 Btu	1.34×10^6 Btu	4.29×10^6 Btu
Mar	8317	524	4.36×10^6 Btu	$.50 \times 10^6$ Btu	3.86×10^6 Btu
Apr	8317	245	2.04×10^6 Btu	--	2.04×10^6 Btu
May	8317	74	$.62 \times 10^6$ Btu	--	$.62 \times 10^6$ Btu
June	8317	5	$.04 \times 10^6$ Btu	--	$.04 \times 10^6$ Btu
July	8317	0	--	--	0
Aug	8317	0	--	--	0
Sept	8317	12	$.10 \times 10^6$ Btu	$.48 \times 10^6$ Btu	0
Oct	8317	145	1.21×10^6 Btu	1.59×10^6 Btu	0
Nov	8317	399	3.32×10^6 Btu	1.67×10^6 Btu	1.65×10^6 Btu
Dec	8317	671	5.58×10^6 Btu	1.78×10^6 Btu	3.80×10^6 Btu
Annual Totals		3536	29.42×10^6 Btu	9.06×10^6 Btu	21.12×10^6 Btu

HG1D ANNUAL HEATING REQUIREMENT = 21.12×10^6 Btu

8. HG1D SOLAR COLLECTOR AREA CALCULATION

Qm = I (E) (P.A.) (D.M.) (C.A.)

Where:

Qm = energy available monthly from collector/storage system

I = insolation on exterior of collector at 60 degree angle for clear day @ 40 degree north lat. (Btu/S.F./day) from ASHRAE transactions Vol. 80 Part II

E = efficiency of collector/storage system

P.A. = monthly % of sunshine actually received

D.M. = number of days in month

C.A. = collector area

	I	E	P.A.	D.M.	C.A.	Qm
Jan	1944	.55	.57	31	320 sf	6.05×10^6 Btu
Feb	2176	.55	.58	28	320 sf	6.22×10^6 Btu
Mar	2174	.55	.63	31	320 sf	7.47×10^6 Btu
Apr	1956	.55	.66	30	320 sf	6.82×10^6 Btu
May	1760	.55	.67	31	320 sf	6.43×10^6 Btu
June	1670	.55	.68	30	320 sf	5.99×10^6 Btu
July	1728	.55	.65	31	320 sf	6.13×10^6 Btu
Aug	1894	.55	.65	31	320 sf	6.72×10^6 Btu
Sept	2074	.55	.64	30	320 sf	7.01×10^6 Btu
Oct	2074	.55	.60	31	320 sf	6.79×10^6 Btu
Nov	1908	.55	.60	30	320 sf	6.04×10^6 Btu
Dec	1796	.55	.57	31	320 sf	5.59×10^6 Btu

(8. HG1D Solar Collector Area Calculation)

Using January as the "worst case" month: it can be seen that 320 SF of collectors will provide for HG1D Energy Requirements:

Heating Energy Requirement	=	4.82×10^6 Btu
Average Monthly Domestic Hot Water Energy Requirement	=	1.17×10^6 Btu

Total Energy Requirement from Solar Collectors in January	=	5.99×10^6 Btu
320 SF Collectors provide in January		6.05×10^6 Btu